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# FINAL REPORT

Project No. 450-402-06E

Inter-Agency Agreement FA-65, WAI-96

## ANALYSIS OF DESIGN CHARACTERISTICS OF METEOROLOGICAL TOWER FACILITY

JANUARY 1968



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**FEDERAL AVIATION ADMINISTRATION**  
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by

**U. S. DEPARTMENT OF COMMERCE**  
Environmental Science Services Administration  
Weather Bureau

Atlantic City, New Jersey 08405

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January 1968

Prepared by  
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This report has been prepared for the Systems Research and Development Service, Federal Aviation Administration, under Inter-Agency Agreement FA-65, WAI-96. The contents of this report reflect the view of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification, or regulation.

U. S. DEPARTMENT OF COMMERCE  
Environmental Science Services Administration  
Weather Bureau  
Systems Development Office  
Test and Evaluation Laboratory

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## ABSTRACT

An analysis of design characteristics for an aviation oriented meteorological tower facility is discussed. The feasibility of converting an existing 160 ft. Air Height Surveillance Radar Tower is investigated. The study also incorporates an analysis of the instrumentation required to adequately describe the desired parameters, as well as sensor characteristics, spacing, orientation, and configuration, and the cost of such instrumentation. The feasibility of using the laser and aerosol measuring devices in the tower facility is discussed.

Conclusions support the establishment of the Meteorological Tower test bed with a capability for measuring all parameters of interest to aviation terminal operations.

The mass of the Tower gives it the stability necessary to affix components of transmissometer systems that will aid in slant visibility studies.

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## OBJECTIVE AND SCOPE

The purpose of this report was to furnish guidance to the Federal Aviation Administration in the establishment of design parameters for the subsequent modification and instrumentation of a Meteorological Tower Facility (Metower) test bed at the National Aviation Facilities Experimental Center (NAFEC).

An analysis was made of the instrumentation and configurations required to adequately measure such meteorological parameters as wind, temperature, dewpoint, and visibility profiles; cloud bases; wind shear and low level turbulence; and aerosol constituents of low clouds and obstructions to vision.

The analysis was based primarily on a literature survey. Some limited experimentation was performed to establish the feasibility of affixing transmissometer components to the tower in vertical and slant baseline configurations.

Consideration was given to the usefulness of a surplus radar tower existing at NAFEC to serve as the central point for a Meteorological Tower Facility test bed.



## THEORETICAL CONSIDERATIONS

Current terminal weather measurements attempt to describe the three-dimensional aspects of a volume of space surrounding an airfield. The measurement may be used objectively or through appropriate subjective techniques as reportable weather or it may be used as the basis for a forecast condition. Regardless of use, the current emphasis on increased airport utilization through lower landing minima and short-term terminal forecasts necessitates a better understanding of time and space variations in order to provide a more detailed and useable three-dimensional meteorological description.

Meteorological parameters of primary interest in describing terminal weather conditions to the pilot are visibility, cloud heights and amounts, and wind. In their most useable form these parameters would inform the pilot of inflight and slant visibility conditions while circling the airfield; slant visibility conditions while on final approach; horizontal visibility along the runway; heights of cloud bases and amounts at least to the extent that they would affect inflight and slant visibilities; mean wind speed and direction; and some knowledge of turbulence or wind shear throughout the landing sequence. Some of these types of information are not presently available to the pilot due to a lack of specific measurements or lack of objective techniques for interpreting such measurements.

Consider a portion of the atmosphere as a cylinder centered around a forecast point (F) (figure 1). A meteorological description of the X-Y-Z planes requires a surface observing network on some radius (R) in addition to a vertical profile based on continuous measurement to some height (Z) and random measurement to some height (Z').

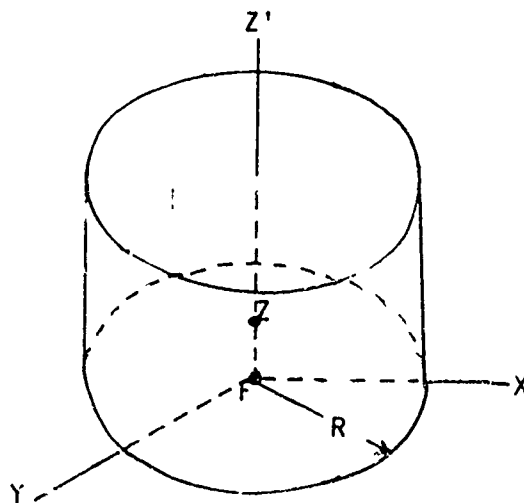


FIGURE 1. X-Y-Z OBSERVATIONAL PLANE

Instantaneous or reportable weather requires observations made at the forecast point (F) where  $R=0$ . When the observation is used as basis for a forecast, broader definition of the X-Y plane is required and R is dependent on such things as the mean wind speed and the forecast time interval desired. Where advective type weather changes are involved, R approximates 5 miles for 10-minute forecast intervals and 30 miles for 60-minute forecast intervals.

Most weather changes that are of importance to the short-term forecast occur in the surface boundary layer. This is considered to be the thin (30-300 ft) layer of air adjacent to the earth's surface where the wind distribution is determined by the nature of the surface and the vertical temperature gradient. Profile measurements to satisfy aviation observations and short-term forecasts should penetrate this surface boundary layer. A single tower rising about 200 feet in the center of the area under consideration would permit continuous measurements up through the Category I-II decision height of 200 ft.

Many cause and effect relationships exist between meteorological variables and the mesoscale weather of airport terminals. The relationships are neither simple nor direct but become quite complex.

For example, consider the reporting of slant or vertical visibilities during radiation fog by means of a subjective technique based on horizontal transmittance. Radiation fog is formed by nocturnal cooling of the air near the surface to its dewpoint temperature. A knowledge of the temperature and dewpoint cooling rates is desired to select a representative vertical fog-density profile. The cooling rates, however, are influenced by:

- a. horizontal and vertical gradients of wind, temperature, and dewpoint for transport of heat or drier air into the area.
- b. transport of water vapor into the ground as dew.
- c. rate of cooling of the ground from net outgoing radiation.
- d. the presence of clouds that would affect radiation.
- e. the conduction of heat from deeper soil to the surface if the conductivity coefficient of the soil and temperature gradient in the soil are known.
- f. the conductivity coefficient for the air/soil surface.
- g. the degree of surface cooling or moisture spread upwards due to turbulent mixing.

The measurement of wind profiles to determine low level turbulence is equally as complex. Table I attempts to show inter-relationships in terms of parameters of interest to the pilot. The relative importance of each measured variable varies with the objective and even then may be judged significant or not significant only as a result of extensive data analysis. For this reason any measuring facility that attempts to investigate surface boundary layer conditions by tower profiles should have a total measuring capability.

Tower mounted instruments can be subject to serious errors. The structure itself will react to the environment and give rise to unknown effects. These errors are a function of the wind speed and direction in addition to the distance away from the tower. To lower the influence of the tower on the parameter being sampled, the mass of the tower should be kept at a minimum.

The errors in tower mounted instruments are noted more in wind speed and direction than in any other parameter. Determination of these errors and attempts to minimize them have been shown by Moses and Daubek<sup>1</sup>; Gill, Olsson and Suda<sup>2</sup>; Munn<sup>3</sup>; Thornthwaite, Superior and Field<sup>4</sup>; and by many others. Most authors recommend that tower mounted wind instruments should be on booms that have a length at least equal to the diameter of the tower. It has been shown<sup>1</sup> that wind instruments mounted in the lee of a tower may give values of only 50% for a light wind and of only about 75% for winds of 10 to 14 miles per hour. Under conditions of radiation fog, the wind may be expected to be very light. A development of a wind too light to be detected by any instrument in the tower shadow could be highly significant. Since the wind is the most important variable to be investigated and since all other information will probably be correlated with it, the wind data must be as unaffected by the tower or other local effects as possible.

The shallower the probe into the atmosphere, the greater the need for accuracy and relative accuracy between levels becomes more important than the absolute accuracy. Wind instruments mounted at different levels on a tower should have as near as possible identical calibration curves. This is so that their reaction to fluctuations is identical. The same is true for temperature, dewpoint, and other parameters that are measured simultaneously at different levels.

TABLE I

INTERRELATIONSHIPS BETWEEN METEOROLOGICAL VARIABLES AND PARAMETERS OF INTEREST TO THE PILOT

VARIABLE MEASURED  
OR DETERMINED - - - - -PARAMETER OF INTEREST  
TO PILOT, REPORTED OR  
FORECAST

| PARAMETER OF INTEREST<br>TO PILOT, REPORTED OR<br>FORECAST | PROFILE DATA | SURFACE NETWORK DATA | TEMPERATURE | DEWPOINT | HORIZONTAL WIND | VERTICAL WIND | ATMOSPHERIC<br>TRANSMITTANCE | CLOUD HEIGHTS | CLOUD AMOUNTS | CLOUD MOVEMENT | APPROPRIATE<br>MATHEMATICAL CONSTANT | SOLAR RADIATION | SOIL TEMPERATURE | AEROSOL MEASUREMENTS |
|--|--------------|----------------------|-------------|----------|-----------------|---------------|------------------------------|---------------|---------------|----------------|--------------------------------------|-----------------|------------------|----------------------|
| CLOUD HEIGHTS  | X            | X                    |             |          |                 |               |                              | X             |               |                |                                      |                 |                  |                      |
| CLOUD AMOUNTS  | X            | X                    | X           |          |                 |               |                              |               | X             |                |                                      |                 |                  | X                    |
| CLOUD MOVEMENT   | X            | X                    |             |          | X               |               |                              |               |               | X              |                                      |                 |                  |                      |
| CIRCLING VISIBILITY<br>AIR TO AIR and<br>AIR TO GROUND     | X            | X                    | X           | X        | X               | X             | X                            | X             | X             |                | X                                    | X               | X                | X                    |
| APPROACH VISIBILITY<br>AIR TO APPROACH LIGHTS              | X            | X                    | X           | X        | X               | X             | X                            | X             | X             |                | X                                    | X               | X                | X                    |
| HORIZONTAL VISIBILITY<br>RUNWAY LIGHTS                     | X            | X                    | X           | X        | X               | X             | X                            |               |               |                | X                                    | X               | X                | X                    |
| MEAN WIND SPEED<br>AND DIRECTION                           | X            | X                    | X           | X        | X               |               |                              |               |               |                | X                                    | X               | X                |                      |
| VERTICAL WIND SHEAR  | X            |                      | X           | X        | X               | X             |                              |               |               |                | X                                    | X               | X                |                      |
| TURBULENCE (GUSTINESS)                                     | X            |                      | X           | X        | X               | X             |                              |               |               |                | X                                    | X               | X                |                      |
| LARGE VERTICAL DRAFTS                                      | X            | X                    | X           | X        | X               | X             |                              |               |               |                | X                                    | X               | X                | X                    |

## PRACTICAL CONSIDERATIONS

### (A) Tower.

(1) Description. The Air Height Surveillance Radar (AHSR-1) Tower (Figure 2) has a geographical location of  $39^{\circ}26'37.63''\text{N}$ ,  $74^{\circ}35'51.87''\text{W}$ . It has a structural steel framework of conventional design. At the present the northern face is enclosed, but modifications outside the scope of this report specify that it be stripped of unnecessary additions. The end product will be basically the bare tower structure.

The top of the foundation is 62 ft. above sea level with the tower rising about another 160 ft. An elevator runs to near the top. The base of the tower forms an equilateral triangle with 43 foot sides. This dimension remains constant to the top of the tower.

Two one-story buildings are nearby. Building #171 is approximately 60 ft. southeast of the tower. It is anticipated that space will be available in this building for control systems and recorders.

(2) Discussion. The AHSR-1 tower is only 160 ft. high, but it can give valuable meteorological information. The 160 ft. height will include most surface boundary layer conditions. Mass flow at the top of the tower will be much more representative of flow over the general area than can be determined from a series of surface stations.

The addition of another 70 to 100 ft. would increase the potential of the facility to extrapolate profile data through the use of lapse rates and power laws, and also allow continuous monitoring of Category I-II meteorological conditions. The additional height can be obtained by mounting a self-supporting or guyed crank-up tower on the existing structure.

The main assets of this tower are its width and its mass. It offers a stable platform that could, if needed, provide more than 700 square feet of working space at eight levels. This will allow the mounting of meteorological sensors that would be too large to mount on standard radio/TV type towers. In addition, its mass gives the stability that is required for certain instruments such as a transmissometer.

From the safety standpoint, this tower is ideal. Because of its width and stability, personnel engaged in meteorological observations or maintenance of equipment could perform their duties with a minimum of psychological effects that are usually associated with work at heights above the ground.

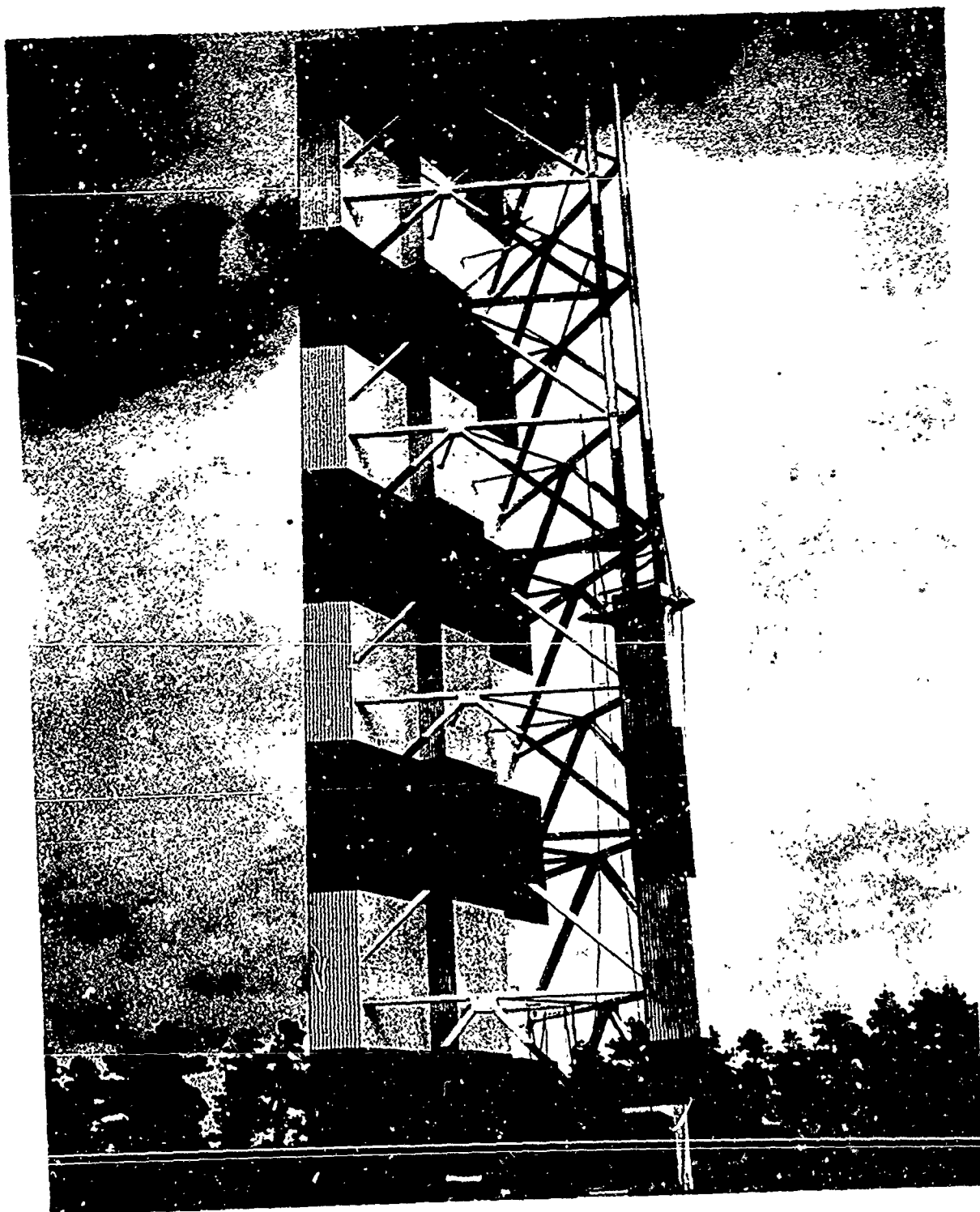


FIGURE 2. THE AIR HEIGHT SURVEILLANCE RADAR (AHSR-1) TOWER  
AT NAFEC, ATLANTIC CITY, NEW JERSEY

The location of this tower with respect to NAFEC is also of major consideration (Figure 3). This site is easily accessible with present personnel and equipment. The tower location with respect to the Atlantic City Mesonet and the Upper Air Facility makes it a central location from which to obtain continuous vertical profiles. The Mesonet System (Figure 4) includes 13 stations arranged in a general concentric pattern around NAFEC at approximate radii of 5 miles, 10 miles, and 20 miles. Each of these stations operates on an automatic basis with a maximum observational rate of one complete observation every 24 seconds. These observations include cloud height, visibility, wind speed and direction, temperature, dewpoint, pressure, and precipitation. The Upper Air Facility is available on demand for random measurements of temperature, relative humidity, pressure and wind to heights not available by tower measurements. The inclusion of these systems as part of the Metower Facility will give a three dimensional view of the atmosphere on the mesoscale for the NAFEC area.

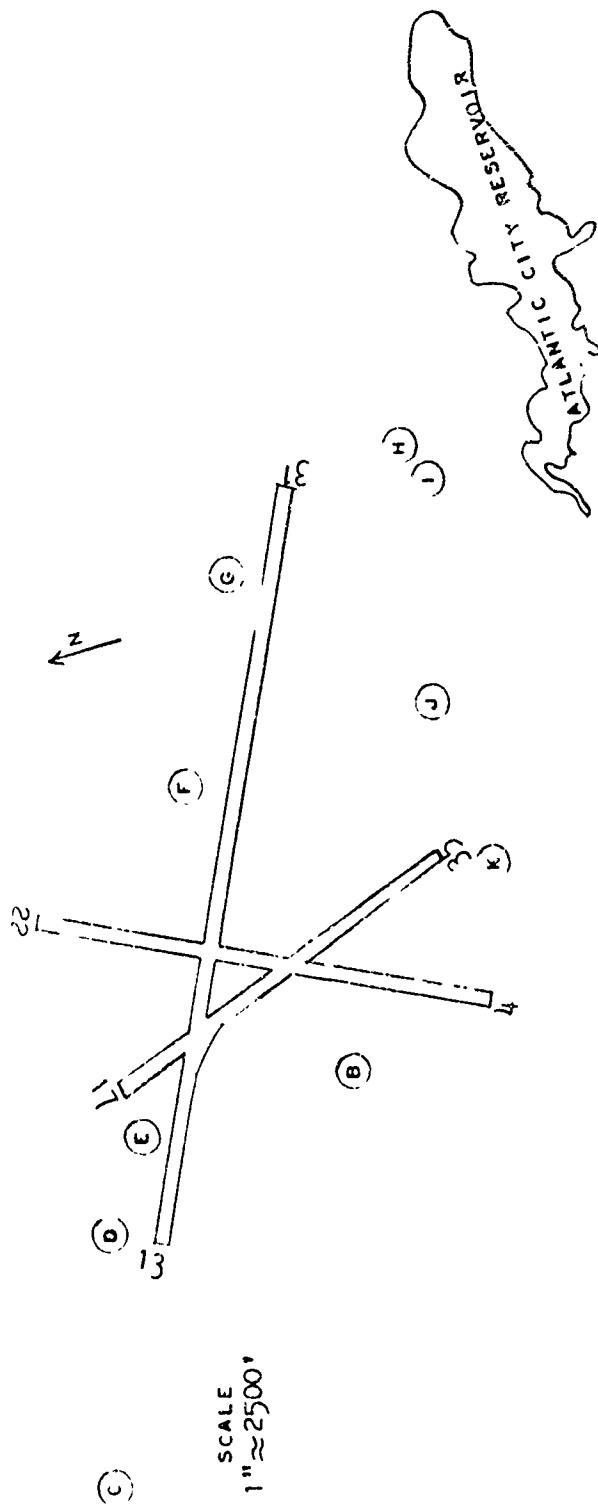
(B) Topography and Vegetation. The terrain in the immediate vicinity of the AHSR tower is slightly uneven (Figure 5). Within 250 ft. to the north there is a drop of about 15 ft. This is also the maximum height variation within 1000 ft. Two one-story buildings are on the surrounding plot. Building #171 is approximately 60 ft. southeast and Building #170 is 210 ft. southwest of the tower.

The clearing surrounding the tower is mostly sand and gravel covered with weeds. This clearing extends to about 150 ft. north, 550 ft. east, 650 ft. southwest, and 200 ft. northwest. The trees surrounding this clearing consist mostly of oak and pine, 30 to 40 ft. high, and extend in all directions for another 1000 ft. or more. This surface and vegetation is typical of southern New Jersey.

The Atlantic City reservoir is about two miles east of the tower (Figure 3). This reservoir covers about 85 acres and will have an effect on the formation of radiation fog and on the character of turbulence in the NAFEC area.

Southern New Jersey can be considered relatively flat. The terrain slopes gently upward from sea level near the coast to heights of about 100 ft. twenty miles to the west. Bays and marshes extend outward from 5 to 10 miles to the northeast through the southeast. The Atlantic Ocean lies about 10 miles southeast. The surrounding area is mostly forested with oak and pine.

(C) Significant Climatology. Hourly weather observations for a 10-year period (January 1949 - December 1958) were obtained to determine the prevailing wind direction under specific



- LEGEND
- A METOWER AND BUILDING #171
  - B CONTROL TOWER
  - C MIDDLE MARKER AND ROTATING BEAM CEILOMETER
  - D TRANSMISSOMETER SITE T1
  - E TRANSMISSOMETER SITE T2
  - F TRANSMISSOMETER SITE T3
  - G TRANSMISSOMETER SITE T4
  - H MESONET SITE #1
  - I UPPER AIR FACILITY
  - J WSF-57 RADAR
  - K BUILDING #137, MESONET DATA CENTRAL

FIGURE 3. AIRPORT COMPLEX, NAFEC, ATLANTIC CITY, N.J.



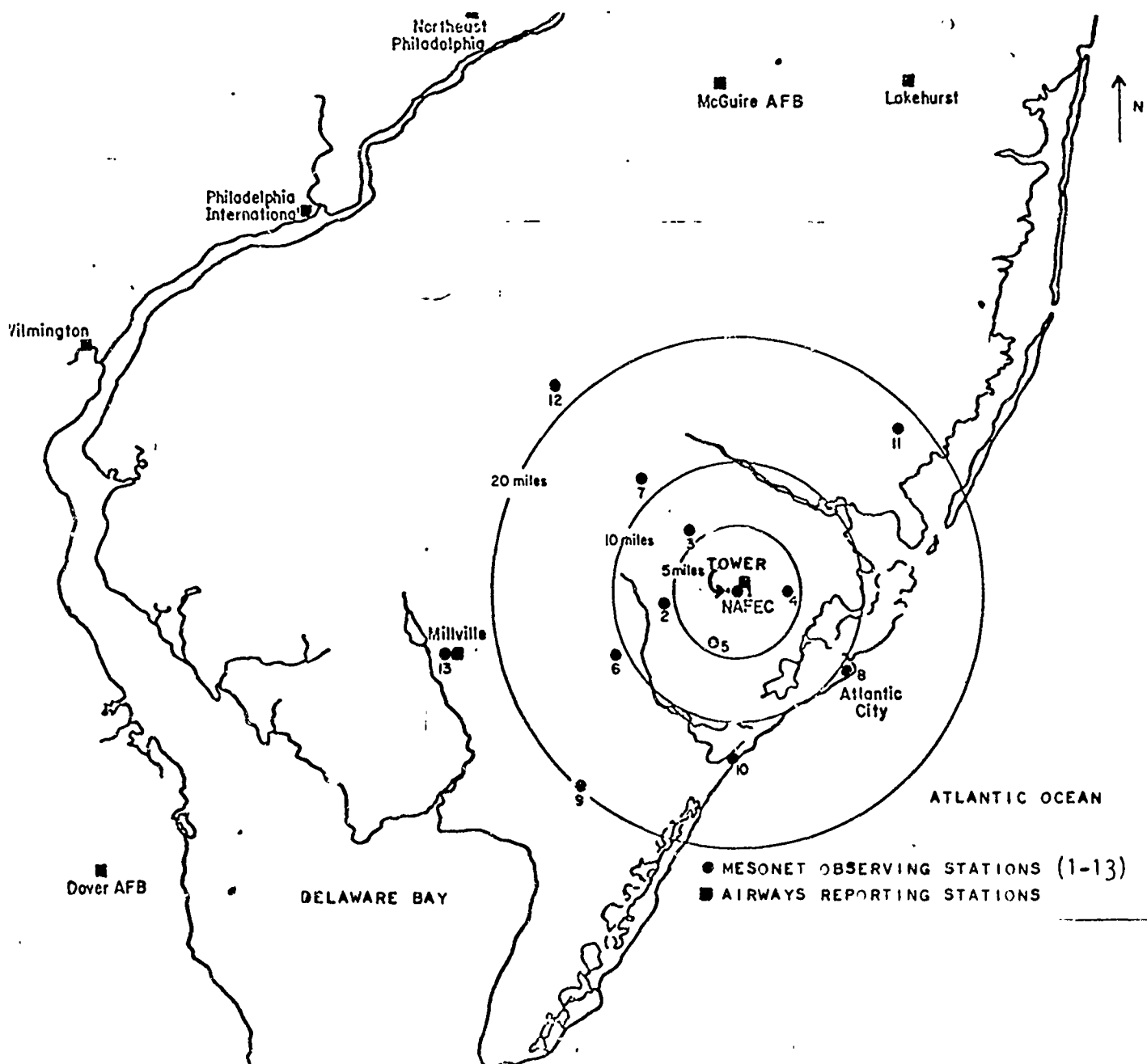


FIGURE 4. METEOROLOGICAL SURFACE OBSERVING NETWORK  
AROUND NAFEC, ATLANTIC CITY, N. J.

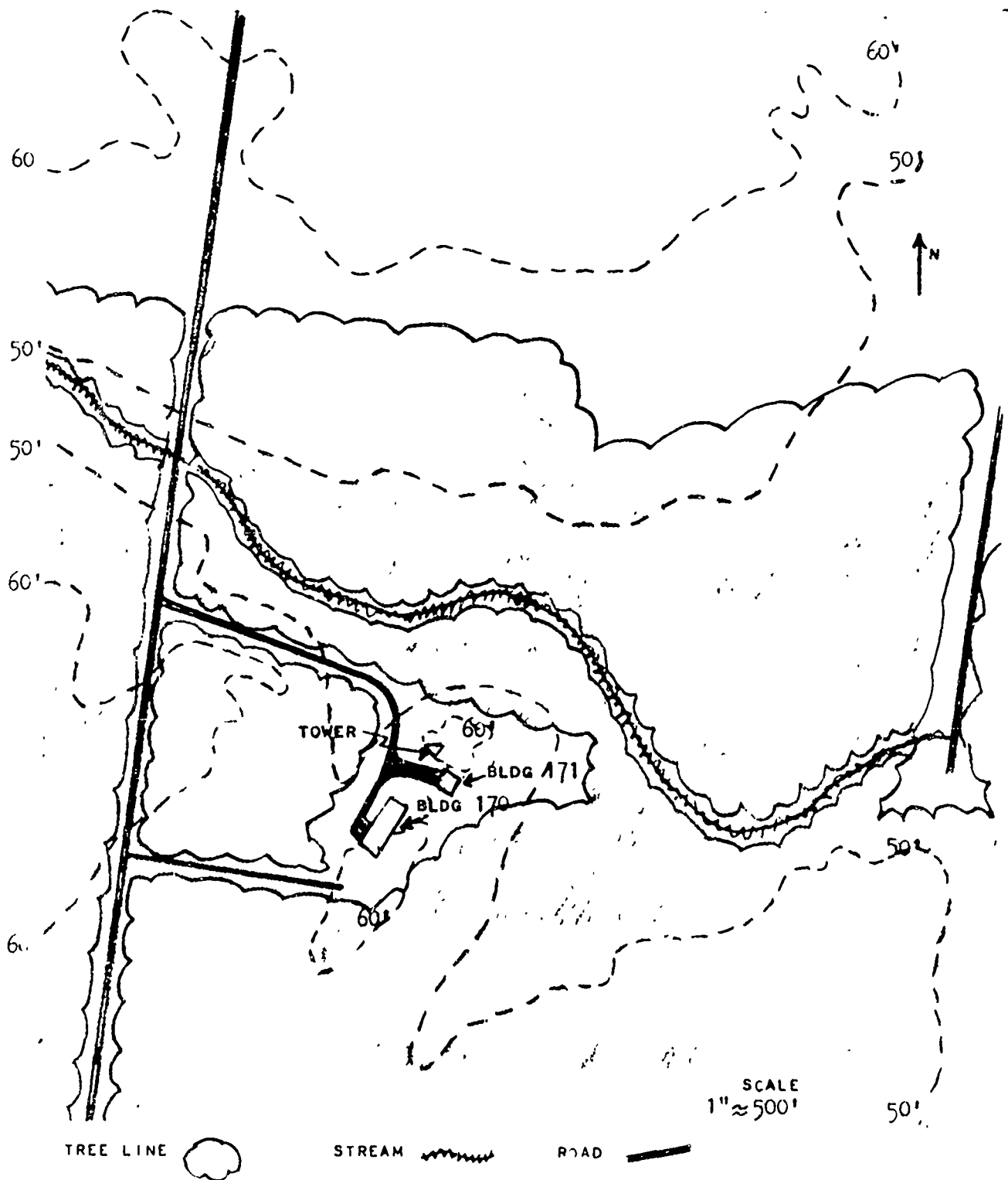


FIGURE 5. TERRAIN FEATURES SURROUNDING AHSR-1 TOWER

conditions to ascertain optimum sensor orientation and to investigate the necessity of dual instrumentation. This wind data applies to a height of 73 ft. above the ground. This is to be considered more representative of profile measurements on the Metower than surface data.

The following results are based on the total of 87,648 hourly observations (Figure 6):

Case I, ceiling 9-500 ft., and/or visibility 0-1 mile. This case was chosen to include Category I-II operations and occurs 9.6% of the total time. The primary occurrence of Case I wind direction is from the east with a secondary occurrence from the south-southwest.

Case II, wind speed greater than 15 knots. This case was selected as typical for studies involving low level turbulence and occurs 8.9% of the total time. Wind direction maximums for this case are from the northeast and northwest.

Case III, wind speed less than 4 knots. This case was selected as typical of radiation fog conditions and occurs 9.0% of the total time. In this case the distribution of wind direction is relatively equal, but maximums are evident from the north and from the southwest.

#### (D) Measurements and Exposure.

(1) Wind. Because of the size of this tower it would not be practical to adhere to the general rule of boom length equal to tower width. Guyed booms of such length would create turbulent wakes and unguyed booms would be susceptible to excess vibration. Errors thus induced would always constitute an unknown factor. An alternative methods that would give representative readings is the use of shorter booms but in a dual installation.

From the significant climatology it can be concluded<sup>5</sup> that good exposure is needed for all wind directions. Studies have shown that the least distortion in wind direction is experienced when the boom is orientated  $\pm 45^\circ$  from the direction of flow. Based on this, and on the orientation of the existing tower, booms extending from both side along the northern face would give representative wind readir under all conditions (Figure 7). This would also give a continuous profile from the side where the tower shadow is at a minimum and ensure accurate measurements under all conditions.

These booms should extend 20 ft. from the tower and be easily retractable without change in orientation to allow sensors to be serviced from the tower proper.

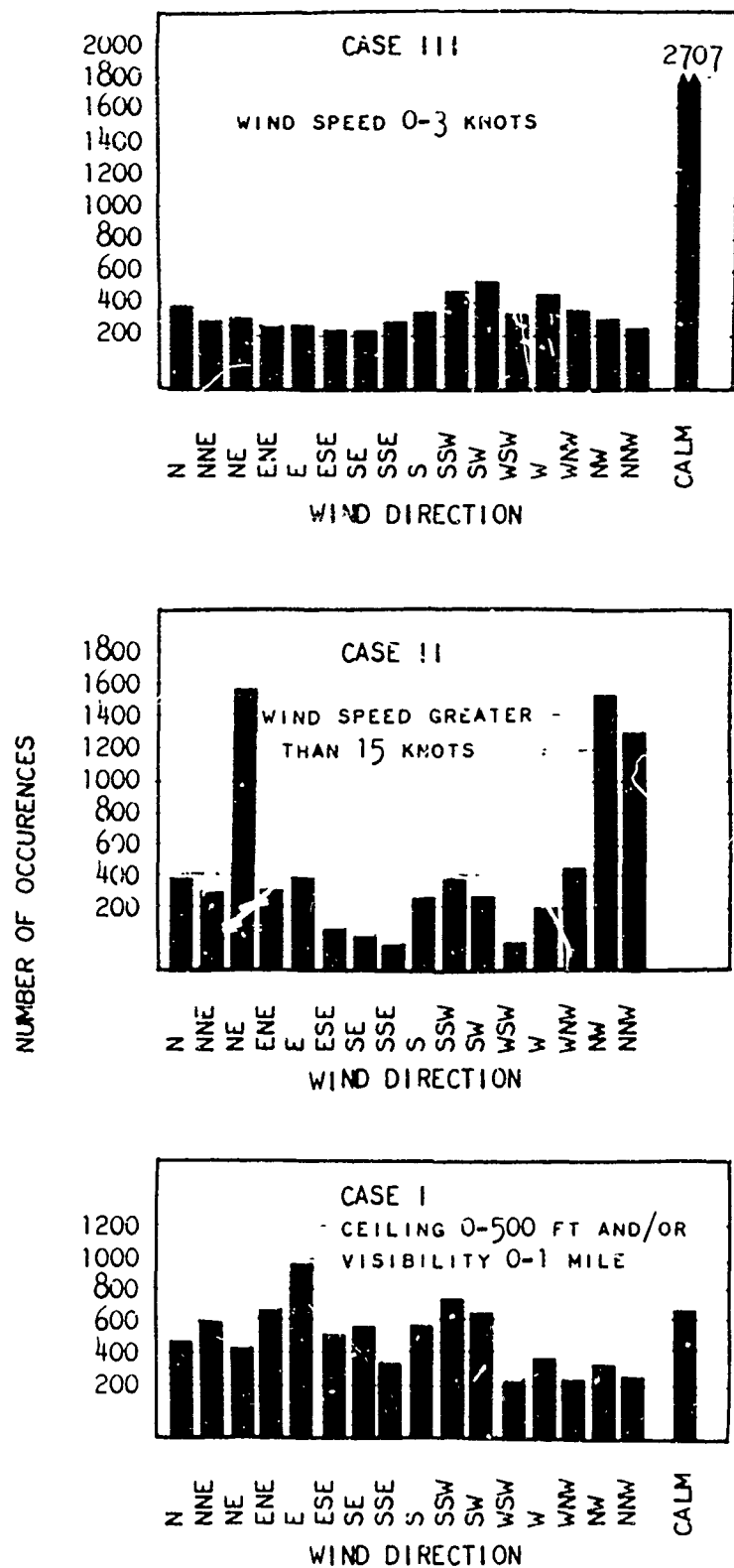


FIGURE 6. CLIMATOLOGICAL DATA BASED ON 87,648 HOURLY OBSERVATIONS AT ATLANTIC CITY, N.J. FROM JANUARY 1, 1949 THROUGH DECEMBER 31, 1958

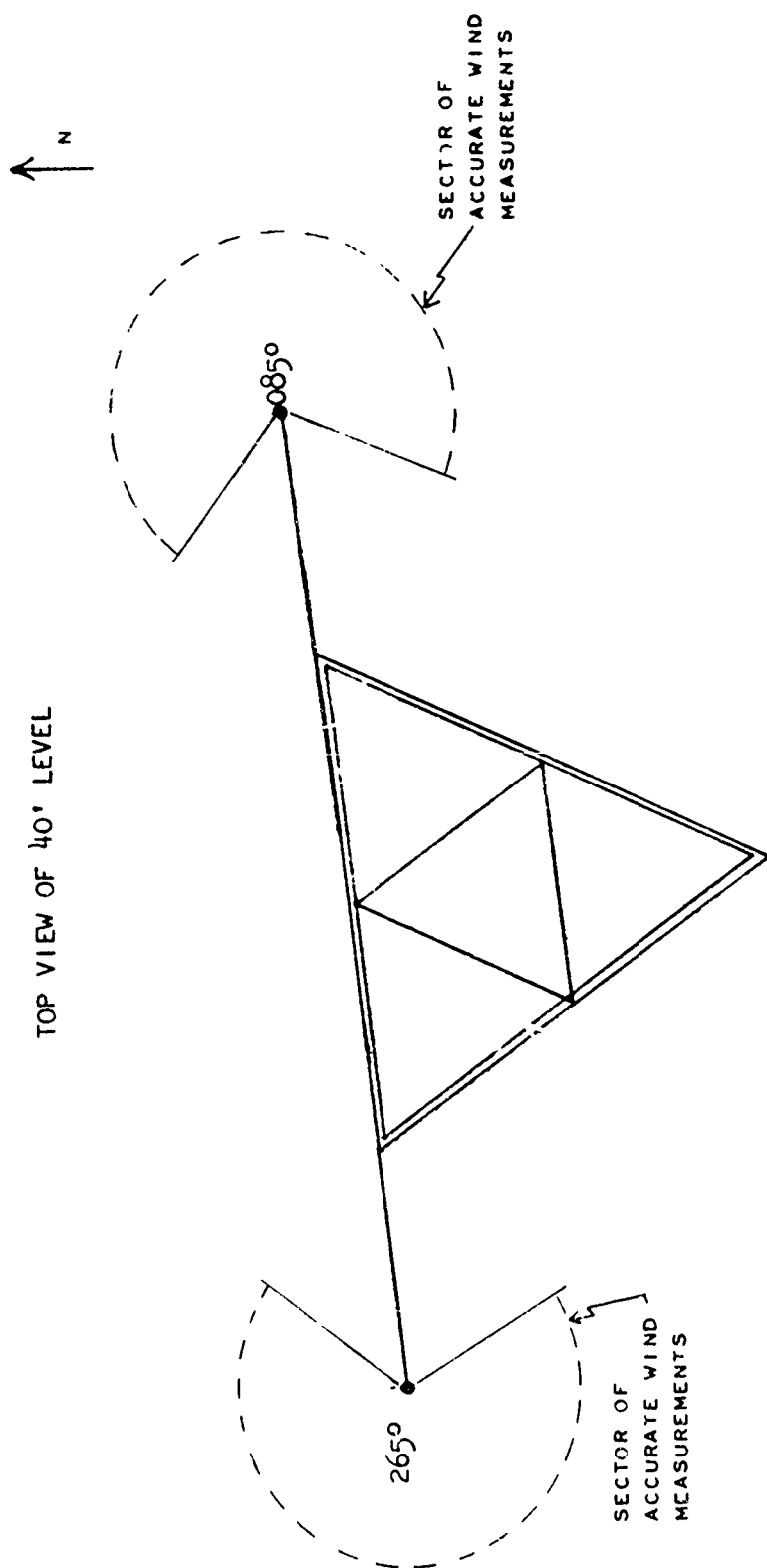


FIGURE 7. OPTIMUM WIND SENSOR ORIENTATION ON AHSR-1 TOWER

Nearby buildings and trees will influence wind measurements in the lowest layers. Obstacles introduce turbulent eddies and tend to reduce the mean wind flow. Measurements made at the surface are needed for studies relating to tower effect and surface turbulence but mean wind flow conditions will not be representative below 40', the average tree height in the area. Horizontal wind speed profiles generally follow a logarithmic increase with height in the surface boundary layer therefore effective measurement levels should be about 6, 40, 80, 160 ft. and the highest tower level assuming the addition of a 70-100 ft. extension (Figure 8).

Areas of convergence, divergence, and turbulence add gustiness to the horizontal flow and introduce vertical motion. Due to nearby buildings and trees measurements of gustiness and vertical motion would not be representative of other more cleared areas but would become representative at about 40 feet. The degree of gustiness and vertical motion in the surface boundary layer can be determined by measurements at the 40 ft. level and at the highest tower level assuming the addition of a 70-100 ft. extension.

Since the platforms are established on the tower, practical consideration of boom height above each platform for ease in maintenance and installation will cause a slight departure from these ideal height values in an actual installation.

Sensors for measuring horizontal wind, vertical wind, and gustiness can all be mounted on the same boom. The grouping, however, should be designed to avoid physical influences.

(2) Temperature and Dewpoint. Temperature and dewpoint profiles should identify discontinuities within the surface boundary layer. The presence and height of inversion levels and abnormal lapse rates have considerable significance in fog and turbulence studies. Sensors should be installed at 6, 20, 40, 80, 120, 160; and 200 ft. and the highest tower level assuming the addition of a 70-100 ft. extension to insure adequate resolution. Tower differential heating effects can be ignored if the sensors are mounted at least 5 ft. from the tower, either on the wind booms or on separate booms, and properly aspirated. Single installations on the eastern side of the tower will be adequate.

(3) Visibility. Visibility determinations can never be completely objective due to the human response factor. Correlation of this human response to surface atmospheric transmittance<sup>6,7</sup> has led to the runway visibility and runway visual range programs. No operational methods exist however for determining slant or vertical visibility through the use of horizontal

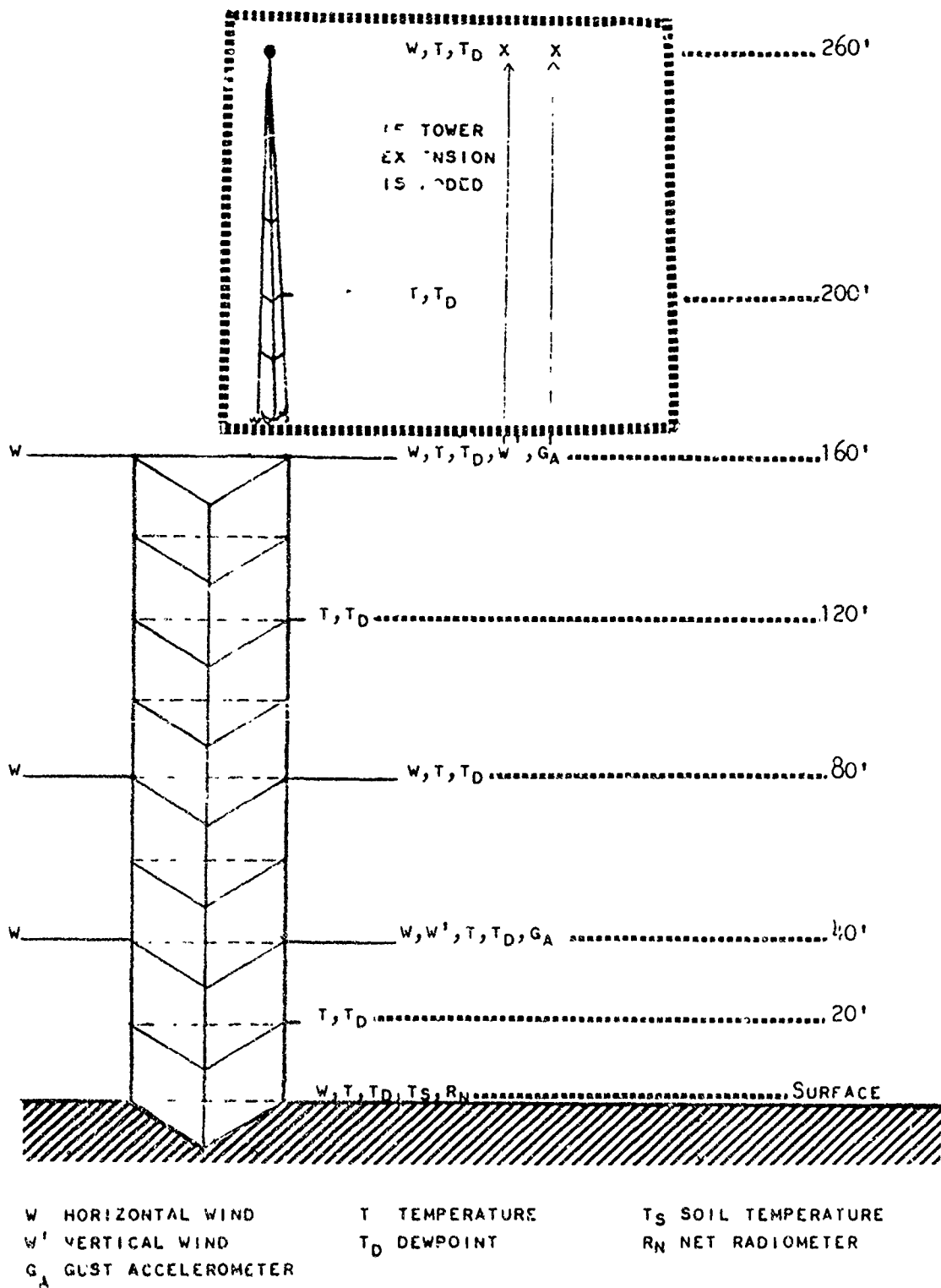


FIGURE 8. PROPOSED INSTRUMENTATION FOR PROFILES OF TEMPERATURE, DEWPOINT, AND WIND

transmittance or slant configurations. Development of techniques for determining these parameters depend on the feasibility of using the current transmissometer system in other than horizontal configurations or the development of new instrumentation.

Tower movement will have a detrimental effect on a transmissometer system. Fortunately, the mass and width of the AHSR-1 tower offers great stability. Maximum design deflection under 40 knot winds is one-half inch. Some movement could be tolerated by using appropriate data analysis techniques.

Attempts were made to determine actual tower movement under wind conditions up to 30 knots. A theodolite was used from the top of the tower to a ground target and from the ground to a tower target. No movement was apparent but the resolution of the theodolite would not detect less than one-quarter inch movements. A feasibility test, using an actual transmissometer installation on the tower, was performed and reported on in Appendix A.

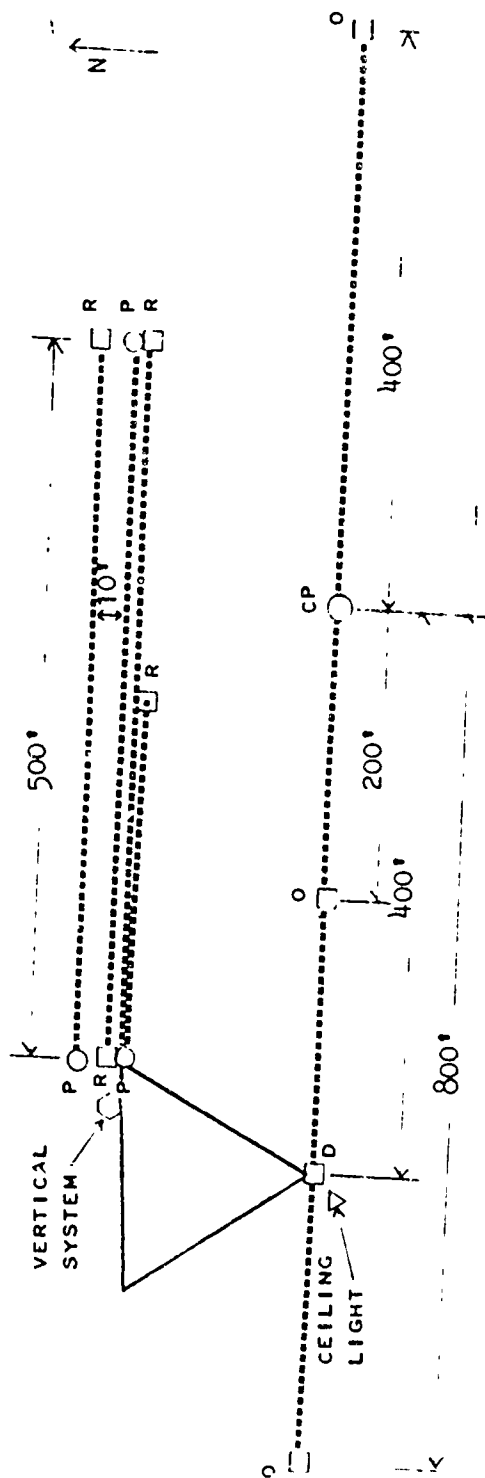
Vertical variations in atmospheric transmittance are an observed fact. Pioneer work done at Cardington, England<sup>8</sup> and London, England<sup>9</sup> established an approximate relationship between slant and horizontal visibility providing the depth of fog was known. Stewart<sup>10</sup> suggests that a more accurate relationship could be found if the temperature and drop size distribution was known. Application of this relationship to approach visibility through instrumental techniques might be developed by a configuration of transmissometers as shown in Figure 9. Two horizontal, two slant, and one vertical transmissometer systems are recommended.

The 6-ft. horizontal system represents the horizontal plane at which the slant and vertical systems terminate. In addition it represents a surface-based observer's line of sight. The 15-ft. horizontal system represents the pilot's theoretical line of sight at cockpit level. Differences in horizontal transmittance between the 6- and 15-ft. levels would be a suitable subject for study.

One characteristic of the current transmissometer system becomes a disadvantage when using the system in slant and vertical configurations; transmittance measurements are integrated values representing all conditions existing within the baseline sampling path. Height information on transmittance discontinuities is not readily apparent. For this reason, additional measurements of horizontal transmittance from 15 feet up through the Category I - II decision height of 200 ft. would be desirable. Three methods of obtaining such measurements can be considered:

(a) Using single-ended instruments such as laser or backscatter devices mounted on the Metower to probe a horizontal





TOP VIEW OF TRANSMISSOMETER-ROTATING BEAM CONFIGURATIONS

- |    |                           |   |                     |
|----|---------------------------|---|---------------------|
| P  | TRANSMISSOMETER PROJECTOR | O | DETECTOR POWER AND  |
| CP | CEILOMETER PROJECTOR      |   | SIGNAL OUTLET       |
| R  | TRANSMISSOMETER RECEIVER  | D | CEILOMETER DETECTOR |

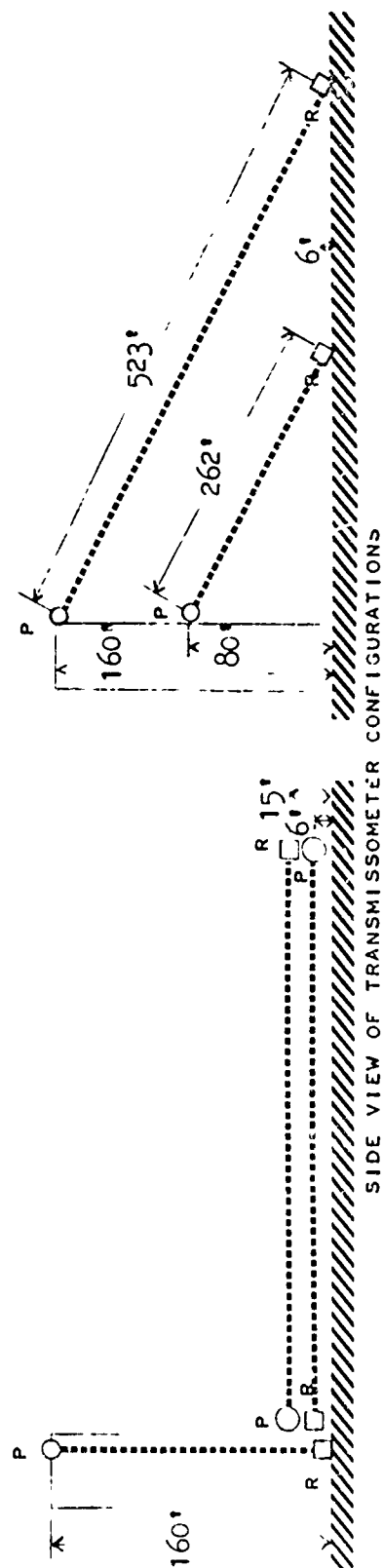


FIGURE 9. TRANSMISSOMETER - ROTATING BEAM CEILOMETER CONFIGURATIONS

plane. Such devices would also simplify the slant and vertical instrument configurations. It does not appear, however, that such devices will become available in the near future. Much development and evaluation work is still required.

(b) Using the current transmissometer system on the Metower by mounting the projector and receiver on adjacent tower legs. This would give a baseline sampling path of about 50 ft. While the transmissometer could be modified to this use, some evaluation work would be required as tower effects on fog structure are still unknown.

(c) Using one end of the current transmissometer system on the Metower and constructing a second stable tower in the area to support the opposite end. This method would allow the use of present instrumentation and tower effects on the sampling path would be minimized. A baseline of 500 feet is suggested.

Although method (c) requires additional construction, it seems to be the preferable choice. Proven methods of transmittance measurement could be made and the instrumentation would be compatible with the other visibility instruments employed in the Metower System.

Transmissometer baselines slanted 18° were selected as being representative of slant visibility angles the pilot might use on approach under very low visibility conditions when in the vicinity of the middle marker. This enables baseline lengths to be set at 262 and 523 ft. and while not an absolute necessity would facilitate comparison of slant transmittances by the mathematical simplicity of  $(t_{262})^2 = t_{523}$  where  $t$  is atmospheric transmittance.

The facility would thus have the capability of exploring the relationship of:

|                    |                 |                    |
|--------------------|-----------------|--------------------|
| $H_{15} : H_6$     | $H_6 : V$       | $V : S_{80}$       |
| $H_{15} : V$       | $H_6 : S_{80}$  | $V : S_{160}$      |
| $H_{15} : S_{80}$  | $H_6 : S_{160}$ | $S_{80} : S_{160}$ |
| $H_{15} : S_{160}$ |                 |                    |

where:

$H_6$  = horizontal transmittance at the 6 ft level  
 $H_{15}$  = horizontal transmittance at the 15 ft level  
 $V$  = vertical transmittance to 160 ft

$S_{80}$  = slant transmittance to 80 ft

$S_{160}$  = slant transmittance to 160 ft

Transmittance measurements by second generation systems would still require an understanding of these basic relationships before operational applications can be made.

The use of human observers to relate transmittance values to slant visibility from the 80 or 160 ft. tower levels is feasible and appropriate. However, in the absence of a specific requirement, no design can be offered because of the many factors which determine the distance at which an object or light is visible. The construction of a visual range to include black objects of various angular size, 25 candelas (c) calibrated unfocused lights, high intensity lights, sky backgrounds, earth backgrounds, etc., would probably result in overdesign.

(4) Clouds. A rotating beam ceilometer with a standard 400-ft. baseline should be installed as shown in Figure 9. With the detector located next to the tower, calibration experiments could be conducted with actual cloud bases substantiated by human observations or by simulation using solid targets or smoke plumes. Proximity to the transmissometer systems will permit studies of ceilometer response to vertical and slant visibilities.

Optimum ceilometer response is a function not only of ceiling height or fog density but also of baseline length. To permit flexibility in studies along these lines, two additional detectors, constructed on portable sleds, could be located at many points along the original baselines as shown in Figure 9. The use of one projector for any combination of detectors would be possible by increasing the projection angle from  $90^\circ$  through  $180^\circ$ . Permanent power and signal outlets need only be constructed at the 200, 400, and 800 ft. locations.

Instrumental values of cloud heights and vertical visibilities can be validated and supplemented by human observations. It would be sufficient to install only 25c. unfocused lights at the 80, 160; and 200 ft. and the highest tower level assuming the addition of a 70-100 ft. extension. To assist in these observations, the observer should have facilities to make balloon measurements in the daytime and ceiling light measurements at night. The ceiling light projector should be located near the permanent RBC detector as shown in Figure 9.

(5) Wind Shear and Low Level Turbulence. The following parameters should be measured to describe low level turbulence and wind shear:

- a. horizontal wind profiles,
- b. vertical wind from sensors at 40 ft. and the highest tower level,
- c. temperature profiles,
- d. acceleration of the horizontal wind from sensors at 40 ft. and the highest tower level,
- e. radiation from sensor at the surface,
- f. soil temperature from sensors at 1 cm. and 10 cm. depths.

Items a, b, and c can be satisfied by use of measurements as discussed in sections 1 and 2.

Item d is required to obtain basic information on the acceleration of the horizontal wind which is related to the degree of turbulence. Two sampling points, one at the first level free of local effects and the second at the highest tower level, will provide adequate information to present a profile of this parameter. Exposure for this instrumentation is basically the same as other wind instruments. It can be mounted on the same booms as the wind instruments but spacing must be sufficient to prevent interaction between sensors.

Radiation information, item e, is required to give additional information on the stability of the atmosphere. For studies of turbulence, it is desirable to have this in the form of net radiation, the difference between incoming solar plus sky and outgoing terrestrial radiation. The instrument must be mounted so that it is free from obstructions from the east-northeast through the west-northwest so that a shadow will not be cast on it at any time. In addition, it cannot be subject to radiation from any other source. If this sensor was mounted on the tower, the exposure for incoming radiation would be excellent; however, the structure itself would present a significant contribution to the outgoing radiation. A sensor mounted near the surface, about 100 ft. east-southeast of the tower would meet the exposure requirements except during the hours near sunrise and sunset when trees in the area would cause shadows. Since turbulence and incoming radiation will be at a minimum during these periods, a surface installation with this exposure will be satisfactory. The sensor should be about 1 meter above the surface so that the radiation is representative of the surface rather than of a thick layer of air above it.

Since the soil acts as a medium for the transfer of heat, studies of turbulence will require measurements of soil

temperature (item f). Soil irregularities prevent representative temperature readings at the immediate surface. Since these conditions become more homogeneous at a depth of about 1 cm., the first observation should be at this point. A second sensor located at 10 cm. would serve to define the heat flux near the earth's surface. These sensors should be located in an area clear of the tower shadow. An enclosed and seeded area about 100 ft. east-southeast of the tower will be satisfactory. This site should be pre-selected and protected so that soil characteristics are not disturbed by construction activities.

(6) Aerosol Constituents. Hygroscopic nuclei are particles that under favorable conditions will undergo growth and become factors in influencing visibility conditions. The constituents of the particles and the concentration of water vapor determine the rate of growth.

The particle size distribution of interest for visibility purposes range from radii of 0.1 micron to about 25 microns. 0.1 micron is the lower limit of particles capable of serving as condensation nuclei. The average radius of droplets in a mature fog is about 10 microns and the maximum radius to be expected in low clouds is 25 microns.

Current short-time prediction techniques do not take advantage of particle behavior as a forecast tool due to the lack of appropriate measurements. To study visibility problems, measurements should be made of particle size distribution and of particle constituents. Profiles of these can be established by making these measurements at both the surface and the 160 ft. level.

Harris<sup>11</sup> states: "Until measurements are made giving the wide range in size distributions as a function of time with the other quantities (total liquid and vapor water content, attenuation, and visibility) it will be difficult to work out the interrelations between the variables and to correlate them with models that have good predictive value of a fog's behavior in space and time."

Complete identification of the atmospheric constituents in the surface boundary is also needed before backscatter type instruments can effectively be calibrated for visibility measurements. This is because of the absorption qualities of some particles such as industrial pollutants.

## INSTRUMENTATION

### (A) General

The system should contain meteorological sensors that are capable of continuous unattended operation except for normal maintenance and calibration. It should also be capable of operating on 115VAC 60 cycle with a  $\pm 10\text{V}$  power variation causing no degradation to the system or operation. For each parameter measured, the sensor design and type should be identical throughout the system.

### (B) Sensor Characteristics

(1) Horizontal Wind: Horizontal wind speed sensors should be of a cup design that operates on a light chopper principle. The direction and speed sensors should be designed so that there is no interaction in their operation.

The data output from the sensor through the recording should meet the following specifications:

|                | <u>Range</u>                 | <u>Accuracy</u> | <u>Resolution</u> | <u>Starting Speed</u> |
|----------------|------------------------------|-----------------|-------------------|-----------------------|
| Wind Direction | $1^{\circ}$ to $360^{\circ}$ | $\pm 5^{\circ}$ | $1^{\circ}$       | 1.0 kt                |
| Wind Speed     | 0 - 99 kts                   | $\pm 1$ kt      | 1 kt              | 1.0 kt                |

This output must make available an average and maximum value for selectable periods ranging from 1 to 10 minutes, and a near instantaneous value.

(2) Vertical Wind: The two primary methods for measuring vertical wind employ the use of either a bivane or an orthogonal type sensor. In an aviation oriented Metower as this, either would provide the basic information. However, if the bivane method is selected, care must be taken to choose an instrument that is rugged enough to endure the elements. Some extra sensitive instruments of this design appear to be of delicate construction and have a reputation of calibration drifts and damage in moderate wind. While these instruments may provide more detailed information, the additional maintenance needed makes them undesirable in this type program.

The data output from the sensor through the recording should meet the following specifications:

|  | <u>Range</u> | <u>Accuracy</u> | <u>Resolution</u> | <u>Starting Speed</u> |
|--|--------------|-----------------|-------------------|-----------------------|
|  | 0-25 kt      | $\pm 5\%$       | 1 kt              | 1.0 kt                |

(3) Temperature: The temperature sensor should have radiation and weather shielding and be aspirated in a manner suitable for the unit. The temperature data output from the sensor through the recording should meet the following specifications:

| <u>Range</u>   | <u>Accuracy</u> | <u>Resolution</u> |
|----------------|-----------------|-------------------|
| -20°C to +40°C | ±0.6°C          | 0.1°C             |

(4) Dewpoint Temperature: Two acceptable methods of obtaining the temperature of the dewpoint from a remote location are in common use. They employ either the lithium chloride principle or the "Peltier" effect. Both provide the same basic information, but there is a considerable difference in acquisition cost. While the systems that employ the "Peltier" effect have a cost 3 to 5 times that of the lithium chloride type, they are claimed to be more accurate. For this project, the additional accuracy is not sufficient justification for the extra expense. It is therefore suggested that the lithium chloride principle is acceptable. The dewpoint temperature data output from the sensor through the recording should meet the following specifications:

| <u>Range</u>   | <u>Accuracy</u> | <u>Resolution</u> |
|----------------|-----------------|-------------------|
| -20°C to +30°C | ±0.8°C          | 0.1°C             |

(5) Soil Temperature: Soil temperature should be measured with a special purpose soil probe, rugged enough to withstand burial for time periods of at least three years. The sensor should be such that with horizontal mounting no part is exposed above the ground, and that lead wires emerge at least three feet away to prevent errors induced by conduction. Either the thermohm or thermistor principle of measurement is acceptable as long as it is compatible with the air temperature measurement employed on the tower. The temperature data output from the sensor through recording shall meet the following specifications:

| <u>Range</u>   | <u>Accuracy</u> | <u>Resolution</u> |
|----------------|-----------------|-------------------|
| -20°C to +40°C | ±0.6°C          | 0.1°C             |

(6) Net Radiation: The two basic types of instruments for obtaining net radiation are the plate or unshielded type and the window or shielded type.

The window or shielded type employs a semispherical window to protect it from dust, condensation, etc. This window appears to be a source of error in the system because of its absorption qualities. It also causes a variation in absorption with tempera-

ture and must be replaced at least every two or three months under normal conditions.

The plate, or unshielded type, appears to be the more desirable of the two. Protection from dust and condensation in this type is accomplished by ventilation, thereby eliminating the window error and allowing it to be temperature compensated.

The sensor should be able to withstand exposure to the elements and have a data output from the sensor through the recorder meeting the following specifications:

| <u>Range</u>    | <u>Accuracy</u> | <u>Resolution</u> |
|-----------------|-----------------|-------------------|
| -0.6ly to 1.4ly | ±2%             | 0.02ly            |

(7) Cloud Heights: The Weather Bureau rotating beam ceilometer, WB Stock No. K-210, should be used for measuring cloud heights. Modifications to the projector will be necessary to permit a projection sweep of 180° rather than the normal 90° sweep. The projector and one detector should be on permanent pads, oriented as shown in Figure 9. The two additional detectors are to be mounted on sleds that have built-in leveling features. A total of three cloud height indicators will be needed to allow use of any combination of projector and three detectors.

Also required will be a supply of 10 gram ceiling balloons; helium, WB model ceiling light, WB Stock No. K-100; and Clinometer, WB Stock No. K-110.

(8) Transmissivity: The Weather Bureau Transmissometer, WB Stock No. N140, should be used for measuring atmospheric transmission. Other instruments, using backscatter techniques, are being developed but are not as yet acceptable due to lack of calibration standards.

#### (C) Special Instruments

(1) Laser: The laser is a first generation instrument that has been successfully applied to meteorological observations and measurements. It can now be used in atmospheric research that with further technical development could eventually lead to its use in operational meteorological observations and measurements.

Tests and evaluations have shown that it is feasible to use the laser in atmospheric observations of clouds, visibility, temperature and dewpoint, wind and turbulence, and aerosols. The preliminary work that has been done with it at the Pacific Missile Range<sup>12</sup> has demonstrated its feasibility as an operational meteorological tool.



All types of clouds through all of the atmosphere have been observed, both day and night, and through multiple layers and rain with the laser<sup>12, 13</sup>. The penetration of clouds is a function of the density and not necessarily the thickness, but this allows a reasonable estimate of cloud tops and thickness. The instrument can also detect concentrations too tenuous to be visible with the naked eye. This has on occasion led to the detection of the onset of stratus an hour or more in advance. Techniques will be developed for the identification of cloud constituents as the laser pulse and its interaction with the aerosols of the atmosphere is explored and understood.

The return from a laser shows the combined effect of scattering and attenuation. As the laser beam penetrates fog or haze, there is a decrease in the amplitude of the return that is a function of the optical path. The measurement of this opens the possibility of its use in determining visibility,<sup>14</sup> horizontal, slant, and vertical. The main advantage offered over present type instruments is the single-end property of the laser. Samples from it would not only be more representative through the visual range, but could also be slanted along the final approach or be in the vertical.

It has been shown<sup>15</sup> possible to obtain low level temperature profiles in an inversion by detection of aerosol concentrations at the base. Other tests have shown that it is feasible to use this instrument to obtain temperature and moisture profiles through the evaluation of scattering and attenuation. Although some information has been realized from this type of observation, an increase in the state of the art is necessary before it can be put to operational use. Detailed information on the absorption line of atmospheric constituents must be obtained before temperature and dewpoint profiles can be evaluated.

Turbulence modifies the refractive index of the atmosphere causing the laser beam to have a fluctuation in amplitude and phase.<sup>16</sup> This allows observations of the movement of aerosols. This method suggests measurement of wind and turbulence along runway approach zones in addition to remote measurement of winds at various heights.

Commercial lasers specifically designed for multiple meteorological observations are not available at the present. A "one-of-a-kind" instrument that enables probes of many parameters with a single laser is the Stanford Research Institute, Mark III, Lidar.<sup>17</sup>

The procurement of a laser from commercial sources for meteorological observations will require either modification to an existing instrument or the design of a new model. This modification or design will depend on the specific program in

which it will be used and the safety level that can be accommodated, therefore making impossible any recommendation or cost estimate at this time.

(2) Sonic Anemometer - Thermometer Systems. Recent refinements in sonic systems such as the Sonic Anemometer - Thermometer (SAT)<sup>18</sup> open the possibility of sonic measurements being useful for vertical wind measurements in turbulence and wind shear studies. Instrumental advantages are, lesser calibration problems than the bivane design, excellent response, and a direct measurement of virtual temperature. The SAT is the first known instrument that combines the sensing of temperature and the three wind vectors to a high degree of accuracy.

However, sonic systems are still first generation systems and as such should not be considered for initial installations in the Metower facility.

(3) Gust Accelerometer. The gust accelerometer is a bridled cup anemometer designed so that an electrical signal is produced for small changes in wind speed. The rate of the changes give an indication of the acceleration of the wind and therefore an indication of the degree of turbulence.

A prototype gust accelerometer has been constructed by G. C. GILL, but is not a production item at present. This sensor offers worthwhile information that would supplement existing wind sensors. If available by development or special order this type of sensor should be included in the basic Metower instrumentation.

(4) Aerosol Measurements. Numerous instruments have been developed for laboratory measurement of particle size and distribution. However, for field measurements in the range of interest, the possibilities become limited.

The simplest, most accurate, and most direct methods involve the measurement of the transmission of light energy at one or more wavelengths. Available light scattering techniques have a range from about 0.05 to 10 micron.

Most other methods either operate outside of the range of interest or take too long for results to be realized or invade the medium being investigated. This invasion destroys the individuality of the aggregate and the sampling will have little or no relationship to the size distribution of the suspension.

The required instrument should identify the constituents, and give a size and frequency distribution for particles in the 0.1 to 25 micron range. This will probably necessitate two

instruments, one for the identification and a second size and frequency information. The instrument(s) should also be capable of frequent sampling rates not to exceed 1 per five minutes.

There are no known instruments specifically designed for meteorological observations of aerosols that give the required information. Instrument modification or design will be required to obtain the needed data, therefore no specific instrument can be recommended or can any cost data be supplied.

The development of two instruments, one for measuring fog droplets and the other for counting condensation nuclei as shown by Schulz, et al,<sup>19</sup> warrants further investigation. As refinements are made to these instruments, they may become useable in the Metower. Two other instruments that may possibly be adapted to this program are the Royco Instruments, Inc., Particle Counter, Model PC-200A, and the General Electric Company Condensation Nuclei Counter.

(D) Data Logging System. Data logging and control equipment should be installed in Building 171. This data logging system should be compatible with a planned system as shown on Pages C-7 to C-18 of the Appendix.

The system should be capable of operation by remote control from the acquisition point. This control should include the selection of observational rates and modes. The observational rate should give a complete observation at intervals of 1, 10, 30, or 60 minutes. The observational modes are:

Mode 1: The observational sequence should begin at the lowest level and proceed to the uppermost level. Each observation should include all horizontal wind direction and speed, temperature, and dewpoint measurements as well as the Julian date, hours and minutes (24 hour clock) of the beginning of the observational sequence. Data output should be in such format and/or code as not to require more than one card for each observation. The time interval to sample and record each observation shall not exceed 20 seconds.

Mode 1A: This mode will be an expanded Mode 1. The observational sequence will begin with Mode 1, but continue and record all of the remaining parameters using additional cards as necessary. Each additional card shall contain the Julian date and time of the initial card of that sequence. The time interval to sample and record the complete observation shall not exceed 50 seconds.

Mode 2: An observation of horizontal wind direction and speed, temperature, and dewpoint measured at a single level

on the tower, the level selected by remote control at the option of the operator. The observation should also include the Julian date, hours and minutes (24 hour clock) of the beginning of the observation. The time interval to sample and record each observation should not exceed 20 seconds.

Mode 2A: This mode will be an expanded mode 2. In addition to the observation of horizontal wind direction and speed, temperature, and dewpoint, the observation will also include the remaining parameters at the selected level. The observation will also include the Julian date, hours and minutes (24 hour clock) of the beginning of the observation. The time interval to sample and record each observation should not exceed 50 seconds.

Final data output should be in the form of standard IBM type punch cards, both punched and printed such as performed by an IBM card punch type 026. Format of the punch card should be such that data from each tower level appears in the same card location throughout observational cycles and in all observation modes. Provision should be made in the system so that the operator may at his option cause the system to omit the recording of any sensor or sensors until that sensor is restored to operation. This provision shall not cause changes in the accepted card format. The data output device should be capable of unattended operation for a minimum of 48 hours.

The data output as recorded and punched shall be in format and/or code that includes the Julian day, hour and minute in addition to the meteorological values. The recorded meteorological values shall be representative of the following integration periods:

| <u>Parameter</u>          | <u>Integration Period</u>   |
|---------------------------|---|
| Temperature               | - Instantaneous   |
| Dewpoint                  | - Instantaneous   |
| Horizontal wind direction | - Instantaneous and one minute average  |
| Horizontal wind speed     | - Instantaneous, one minute average, and one second peak since last observation |
| Vertical wind             | - Instantaneous and one minute average  |
| Gust acceleration         | - Absolute count of 2 knot deviations since last observation                    |

|                  |   |
|------------------|---|
| Soil temperature | - Instantaneous   |
| Net radiation    | - Average value since last observation                  |
| Cloud height     | - Previous 10 scans with two level reporting capability |
| Transmissivity   | - Running one minute average                            |
| Aerosols         | - Instantaneous as pre-selected by the sensor           |

(E) Costs. Sensor costs, per unit, including acquisition, installation, operations, and maintenance, are shown in Table II. For the laser, gust accelerometer, and aerosol measurement instruments no prices are available. The laser, sonic anemometer, gust accelerometer, and aerosol measuring instrument are non-standard; therefore, specific sensors could not be selected or priced. A complete system cost breakout is shown in Appendix B.

TABLE II

SENSOR COSTS PER UNIT

| SENSOR                                    | ACQUISITION | INSTALLATION | ANNUAL<br>OPERATION | ANNUAL<br>MAINTENANCE |
|---|-------------|--------------|---------------------|-----------------------|
| HORIZONTAL<br>WIND                        | \$ 1,000.00 | \$ 500.00    | \$ 200.00           | \$ 100.00             |
| VERTICAL<br>WIND                          | 800.00      | 800.00       | 50.00               | 50.00                 |
| TEMPERATURE<br>AND<br>DEWPOINT            | 1,500.00    | 1,000.00     | 150.00              | 300.00                |
| SOIL<br>TEMPERATURE                       | 60.00       | 50.00        | 5.00                | 15.00                 |
| NET<br>RADIATION                          | 2,000.00    | 100.00       | 50.00               | 50.00                 |
| RBC<br>WITH<br>RECORDER                   | 7,300.00    | 3,000.00     | 400.00              | 200.00                |
| EXTRA<br>RBC DETECTOR<br>WITH<br>RECORDER | 4,200.00    | 1,000.00     | 200.00              | 120.00                |
| CEILING<br>LIGHT                          | 700.00      | 200.00       | 10.00               | 10.00                 |
| TRANSMISSOMETER<br>WITH<br>RECORDER       | 3,600.00    | 3,000.00     | 400.00              | 200.00                |
| DATA<br>LOGGING<br>SYSTEM                 | 20,000.00   | 5,000.00     | 9,000.00            | 5,000.00              |

## CONCLUSIONS

1. The AHSR-1 Tower at NAFEC is suitable for conversion to a Metower Facility.
2. The addition of a 70 - 100 ft. permanent or crank-up tower to the top of the AHSR-1 Tower, while not a necessity, would enhance its measuring capability.
3. For studies of slant visibility and low level wind shear and turbulence, profile (multi-level) measurements should be made of:
  - a. horizontal wind speed and direction
  - b. vertical wind speed
  - c. acceleration of the horizontal wind
  - d. air temperature
  - e. dewpoint temperature
  - f. atmospheric transmittance
  - g. aerosol constituents (identification)
  - h. particle count and distribution by size
4. These profile measurements should be supplemented by measurements of:
  - a. net radiation
  - b. soil temperature
5. For studies of vertical visibility and for calibrating and validating ceilometer observations, measurements should be made of:
  - a. atmospheric transmittance along a vertical baseline.
  - b. atmospheric transmittance along a horizontal baseline.
  - c. heights of cloud bases
  - d. human observations

6. The Metower Facility can serve as a platform to affix components of transmissometer systems.
7. It is feasible but not yet practical to use the laser as a meteorological tool.
8. It is feasible to utilize human observations to corroborate instrumentally derived values of vertical visibility and low cloud heights.
9. It is more desirable to obtain three dimensional wind components by supplementing existing horizontal wind sensors with vertical wind sensors rather than installing separate three dimensional wind sensors.
10. A Metower Facility should be supported by a surface observation network and upper air measurements.



## RECOMMENDATIONS

1. The AHSF-1 Tower at NAFEC be converted to a Metower Facility in accordance with a system designed as summarized in Appendix C.
2. The Metower Facility should be supported by Mesonet sites 1 through 14 and the Upper Air Facility.

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APPENDIX A

TOWER-TRANSMISSOMETER FEASIBILITY TEST

## TOWER-TRANSMISSOMETER FEASIBILITY TEST

Limitations of the transmissometer for tower use stem from its design as a double-ended optical instrument. This necessitates a rigid installation to maintain alignment. The tolerances for movement are specified \* as 0.01 inch for the receiver and 0.1 inch for the projector.

To investigate the feasibility of using a transmissometer system in other than horizontal configurations, two systems were installed on the AHSR-1 tower. The purpose of these experimental installations was twofold. The first was to determine if movement of the tower exceeded the operating tolerances specified, and secondly, if it did exceed the specific limits, could special analysis techniques be developed to validate the information received.

Since the movement of the tower is related to the wind, a wind system was installed 15 ft. above the roof of the tower. This system was mounted high enough above the roof to give an adequate indication of wind force on the tower face.

The first transmissometer system installed had the projector mounted at the 160 ft. level, pointing downward to a receiver mounted at the surface directly below. This gave a baseline of approximately 160 ft. An analog recorder was installed at the surface level.

The field stop of the receiver was enlarged to accommodate a larger filament image. A modification was also made to enable the 160 ft. baseline to have a full scale calibration rate of 4000 pulses/minute as does a standard system. If this modification had not been made, the full scale pulse rate would have been 40,000/minute, which could not be handled with present analog recording instruments.

The modifications and installation were completed at 1600E, April 7, 1967, at which time data acquisition began for the vertical system. The data collection period ended at 1030E, April 14, 1967, giving a total period of 162 hours, 30 minutes. During this period the system was inoperative for about 38 hours, 30 minutes because of maintenance or equipment failure not associated with the tower installation. The usable data available for analysis was 124 hours.

During the data collection period wind conditions were favorable with frequent periods of wind speed greater than 20 knots. The highest recorded wind was a gust of 45 kts. Light

\* U.S. Department of Commerce, Instruction Manual Transmissometer System, Washington, August 1966, P2-3

rain showers occurred during the first 24 hours of data collection but the visibility was generally greater than 5 miles.

Test transmissometer analog data was compared with analog records from an operational horizontal system to establish deviations from normal. If deviations existed, they were to be compared with wind data to correlate the deviation with a wind vector normal to the covered face of the tower.

The data from the vertical system was similar to the operational system in all respects. No deviations were noted, even in wind greater than 30 kts. Figure 1 gives a comparison of the analog records of the vertical transmissometer and wind.

During this period the wind direction (NNW) was nearly normal to the tower face and tower movement, if any, would be most pronounced. As seen in this figure, there is no evidence of tower movement being sufficient to have a detrimental effect on a transmissometer system oriented in the vertical.

Upon completion of the test with the vertical transmissometer system, a system was oriented in the slant. The projector for this system was mounted at the 160 ft. level. It was directed  $40^{\circ}$  below the horizontal to a receiver at ground level about 190 ft. southeast. This gave a slant baseline of 250 ft.

Data acquisition from this system began at 1530E, April 14, 1967, and was terminated at 1000E, April 21, 1967. Data was 100% usable making a total of 162 hours 30 minutes available for analysis.

Fog and/or low clouds affected the transmittance for 32 hours during the acquisition period. There were also frequent periods of wind speed greater than 20 knots.

Figure 2 shows a comparison of the simultaneous records of the slant transmittance and the wind from the top of the tower. There is no evidence of tower movement under these wind conditions affecting the transmissometer. The sinusoidal tendency exhibited by the trace in Figure 2 was the result of a faulty heater in the pulse amplifier unit and in no way is associated with the slant installation.

The data was compared with an operational 250-ft. horizontal system (T3C NAFEC) to establish if deviations from normal patterns existed. As with the vertical system, no deviations were noted, the records were similar in all respects, although the absolute value of the slant transmissometer was considerably lower than the horizontal system during some periods of fog and/or low clouds.



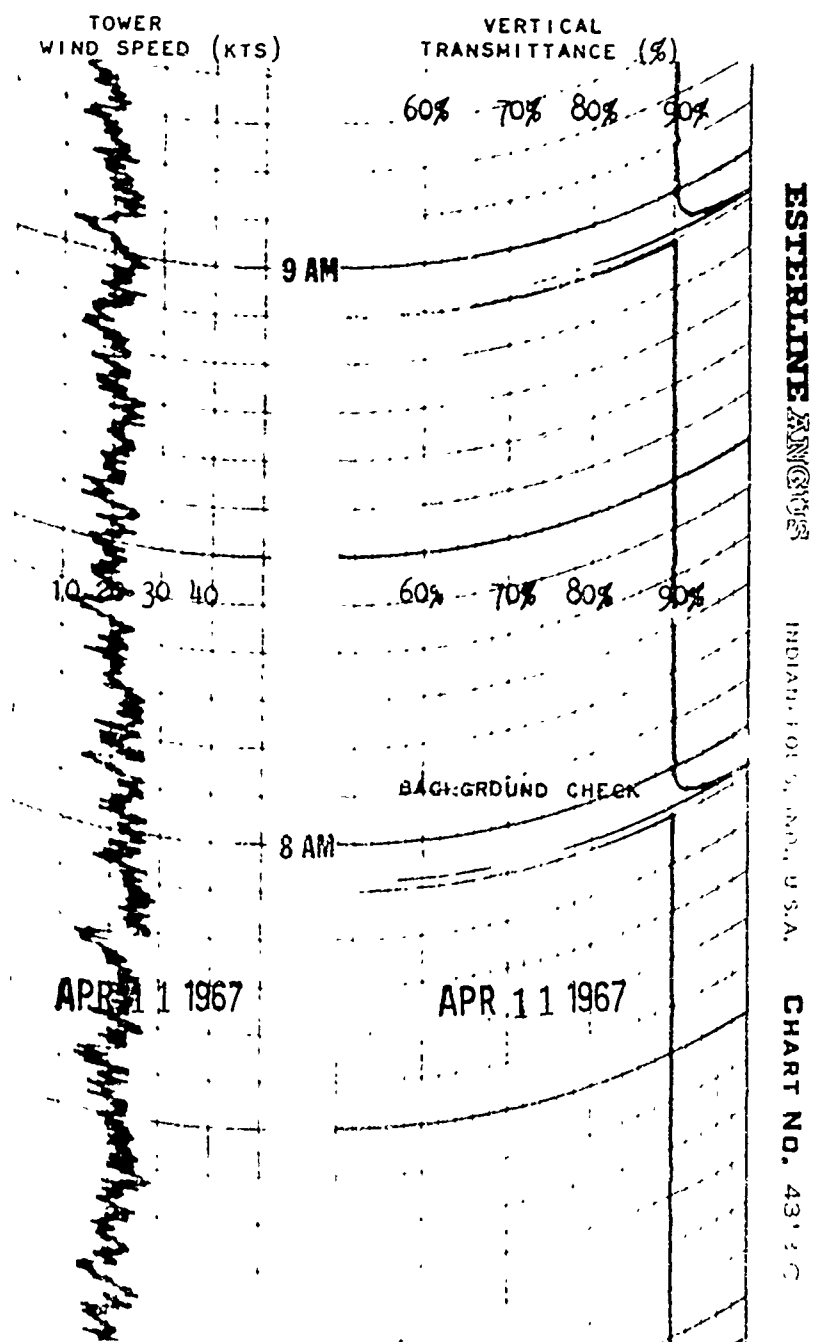


FIGURE 1. PORTIONS OF SIMULTANEOUS RECORDS FROM 160-FT. VERTICAL TRANSMISSOMETER AND TOWER WIND SPEED.

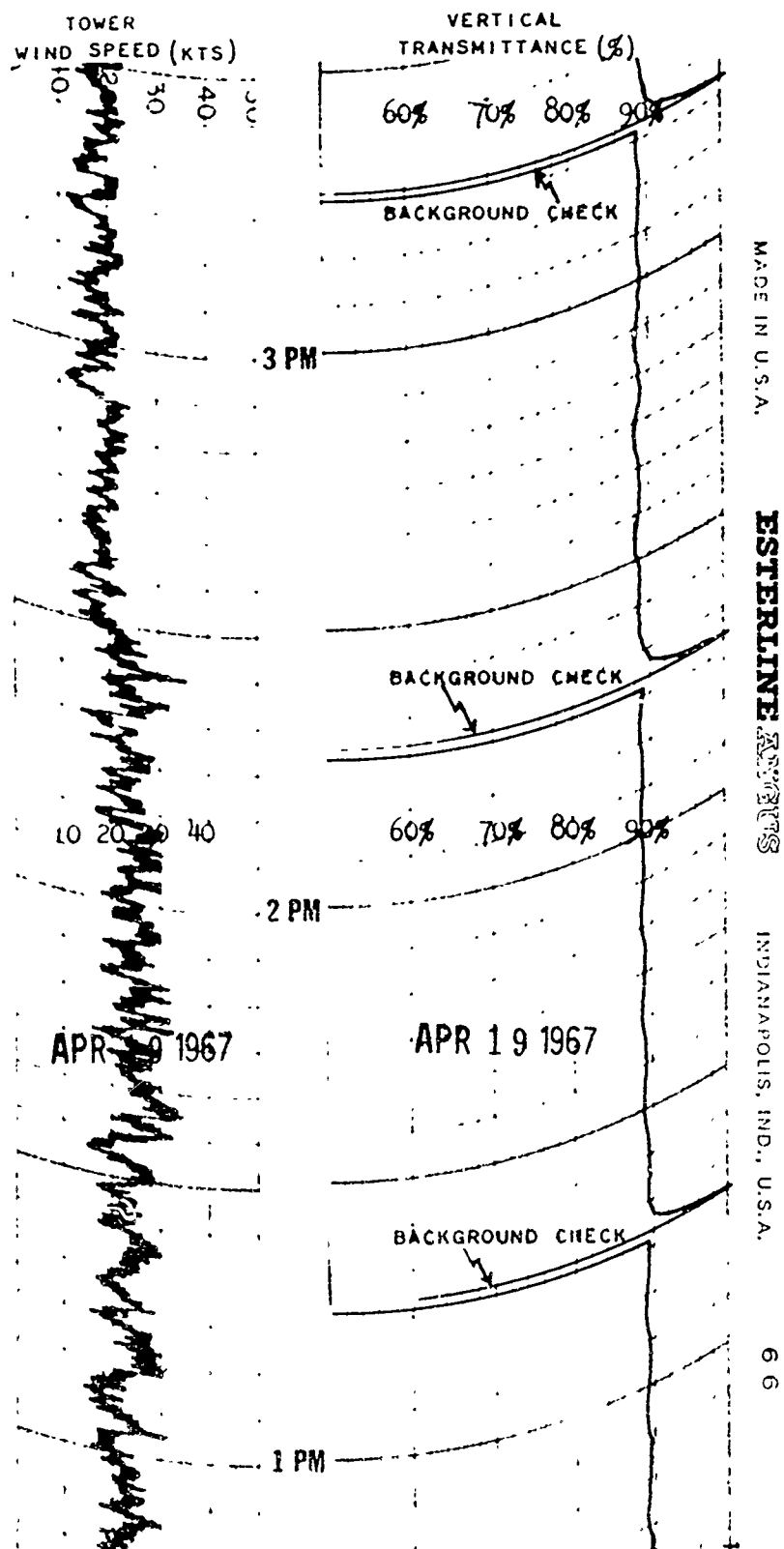


FIGURE 2. PORTIONS OF SIMULTANEOUS RECORDS FROM 250-FT. SLANT TRANSMISSOMETER AND TOWER WIND SPEED.

Figure 3 shows a comparison of the slant transmissometer and a horizontal transmissometer, both having a 250-ft. baseline. The two systems are separated by a horizontal distance of about 8700 ft.

Further studies will be necessary to determine if the difference in transmittance is the result of horizontal separation or the variation of transmittance with height.

From the two experiments conducted it can be concluded that valid measurements can be made with slant and vertical configurations of transmissometer systems.

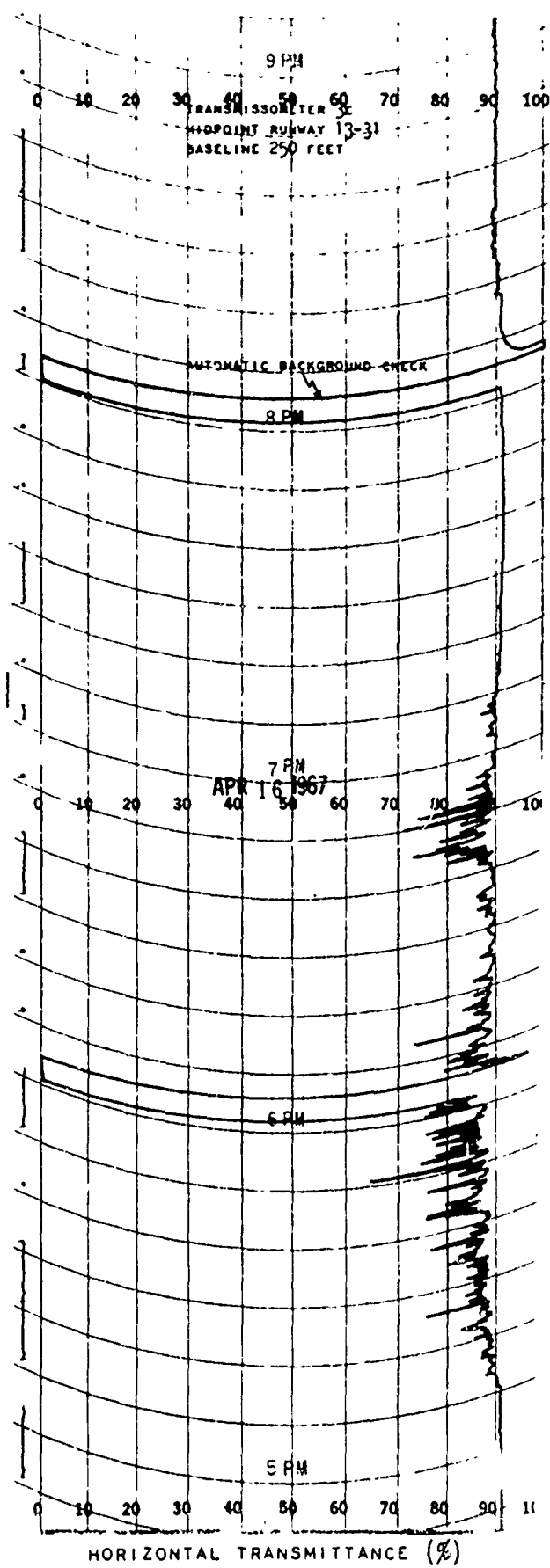
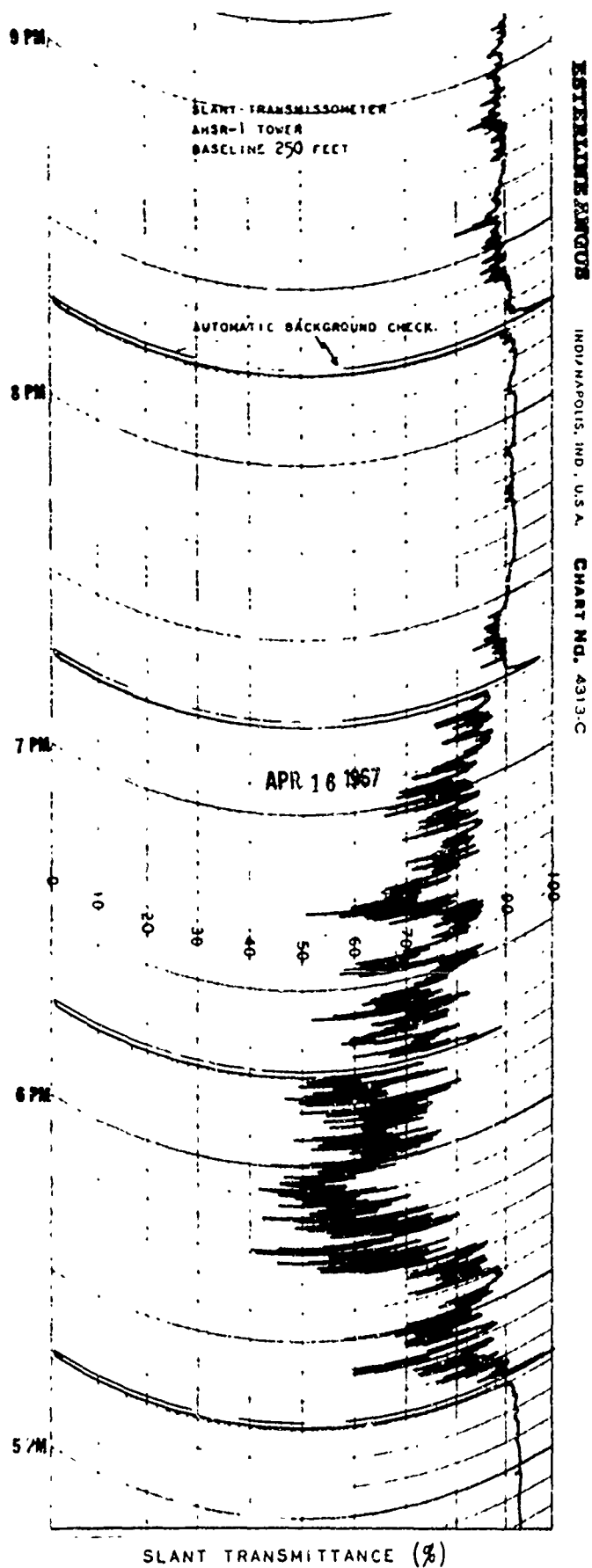
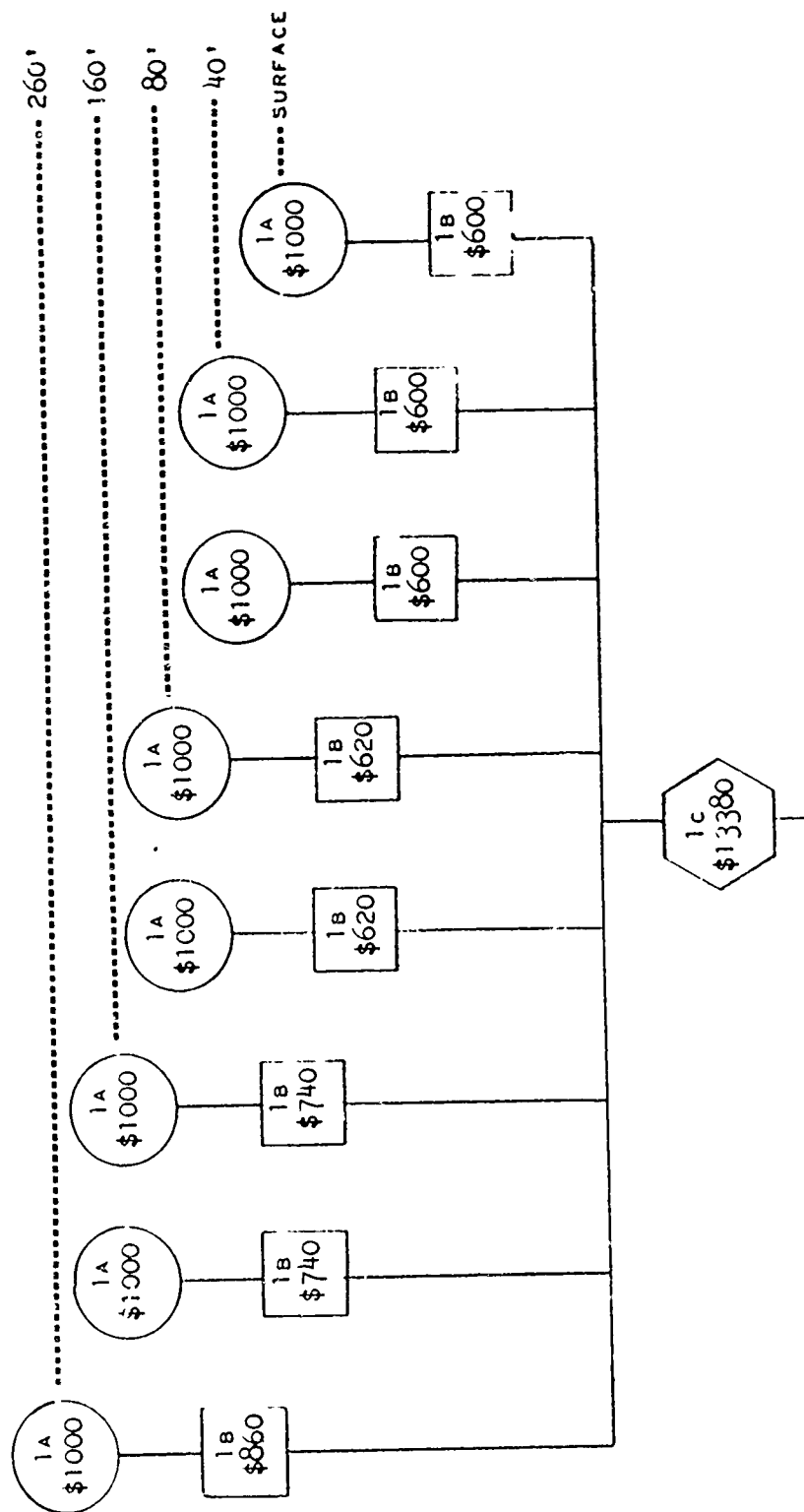


FIGURE 3. COMPARISON OF SLANT TRANSMITTANCE AND HORIZONTAL TRANSMITTANCE.

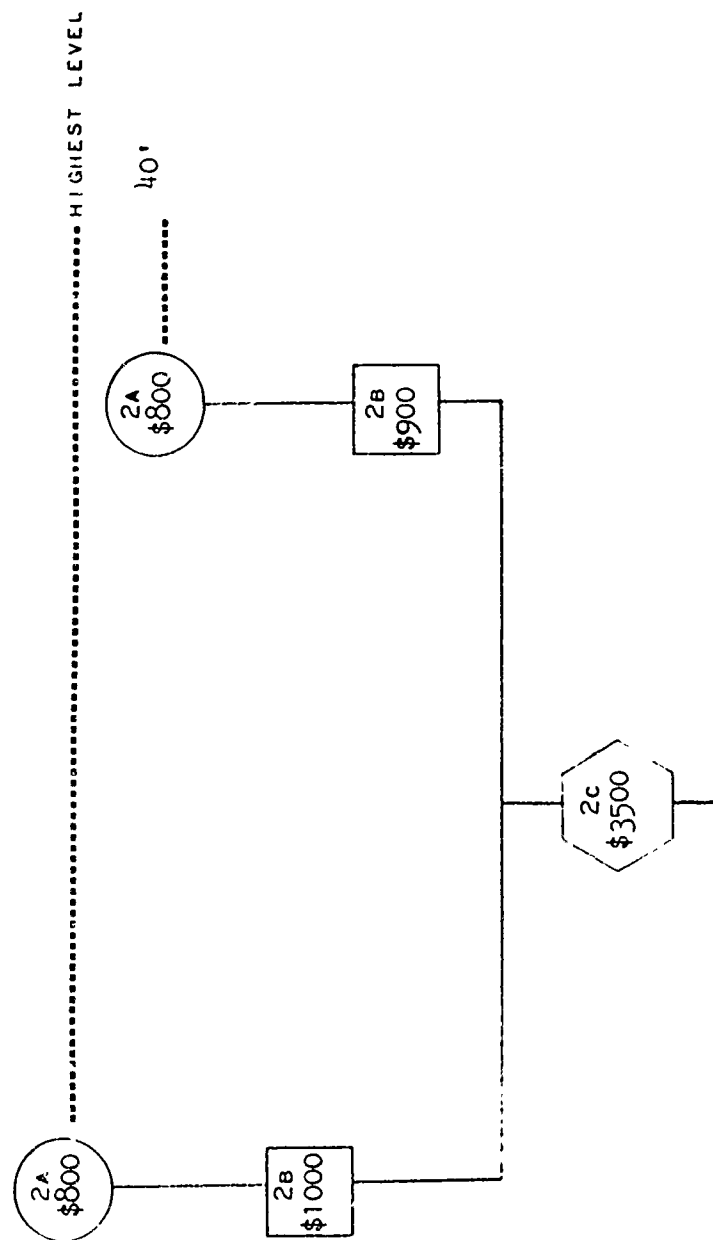
APPENDIX B

SYSTEM COST BREAKOUT

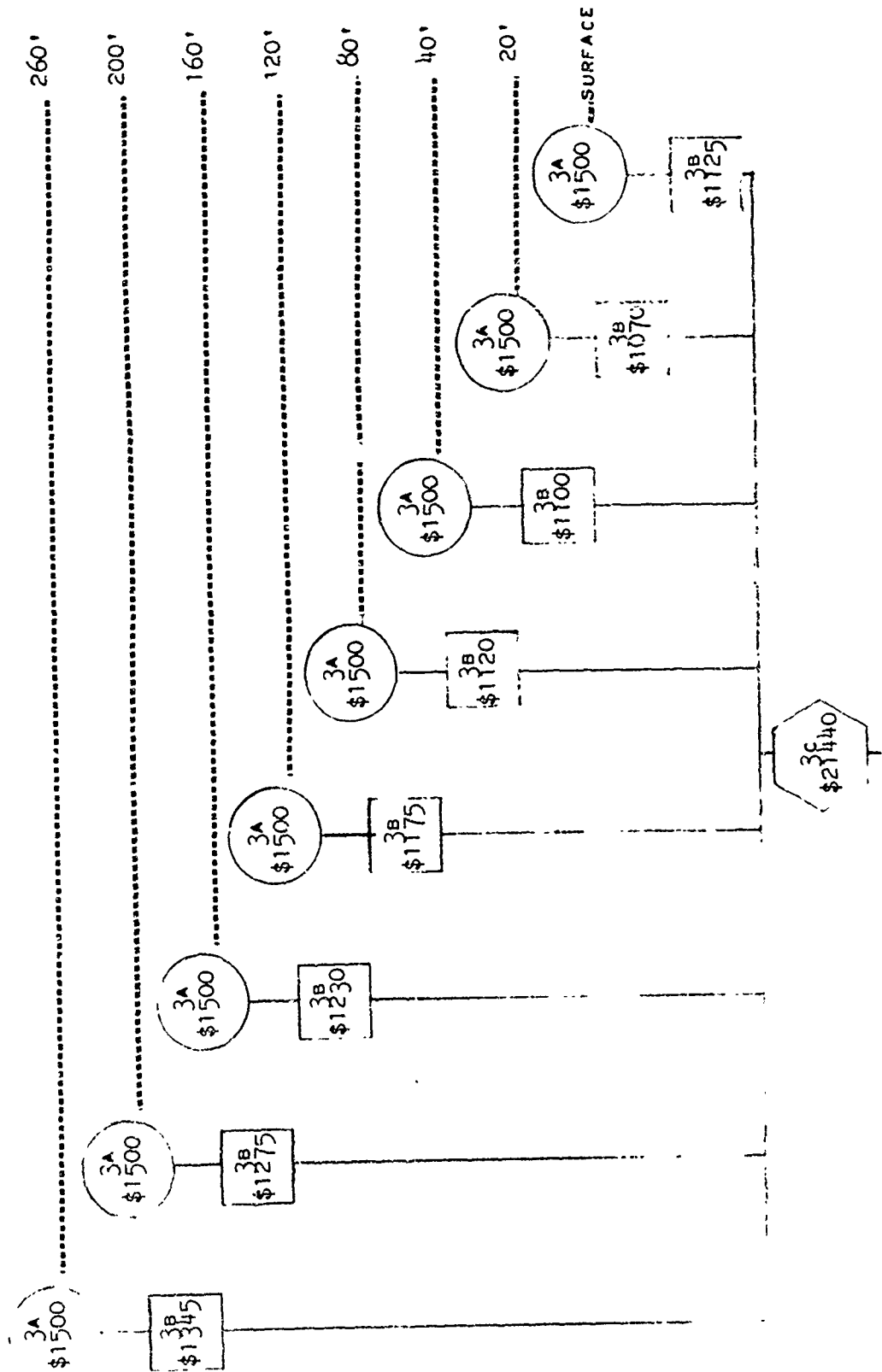
1. HORIZONTAL WIND  
 A. ACQUISITION  
 B. INSTALLATION AND CABLING  
 C. TOTAL



2. VERTICAL WIND  
 A. ACQUISITION  
 B. INSTALLATION AND CABLING  
 C. TOTAL



3. TEMPERATURE AND DEWPOINT  
 A. ACQUISITION  
 B. INSTALLATION AND CABLING  
 C. TOTAL





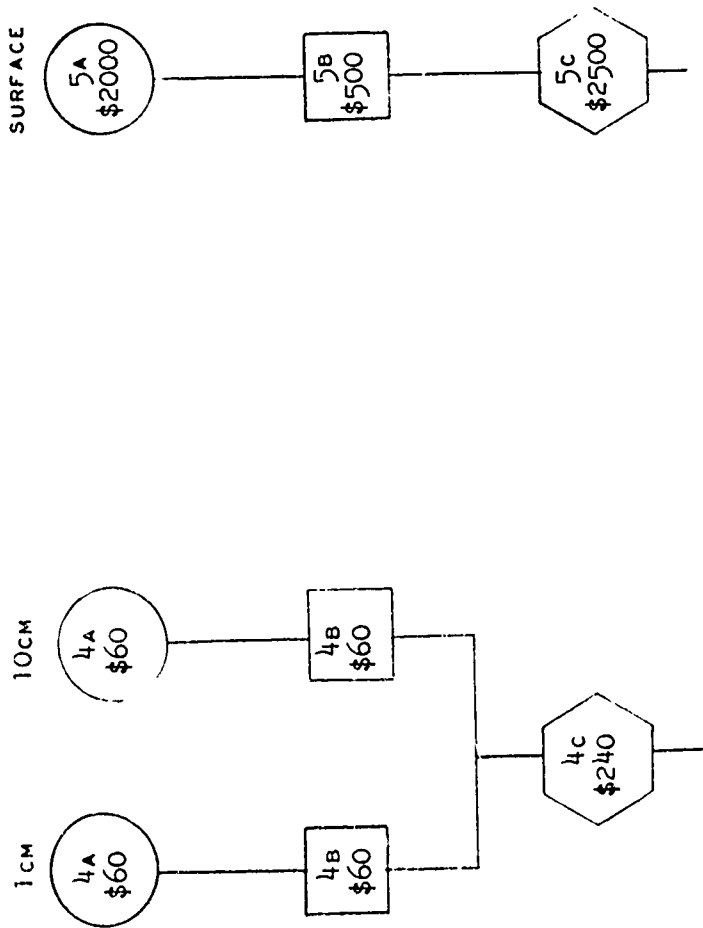
4. SOIL PROBE

5. NET RADIOMETER

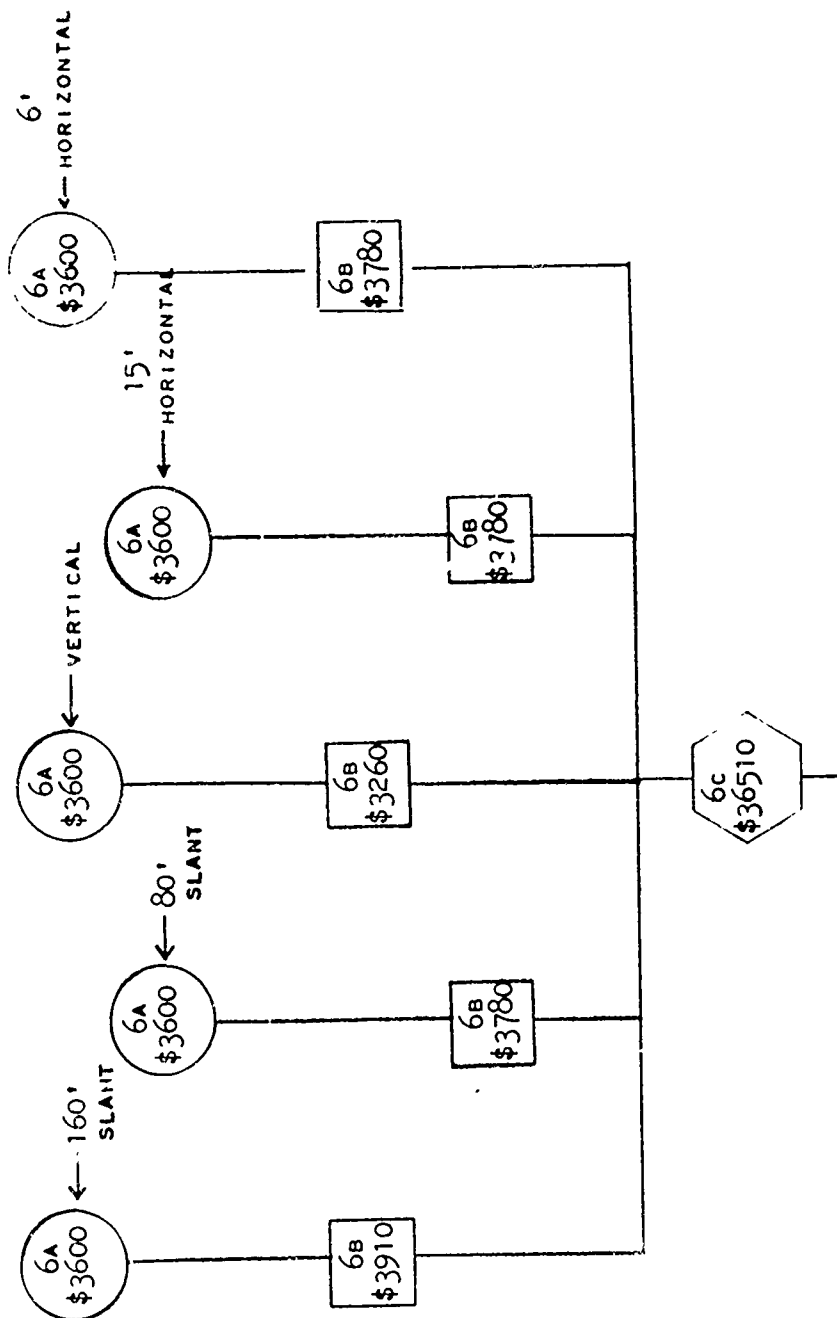
A. ACQUISITION

B. INSTALLATION AND CABLING

C. TOTAL

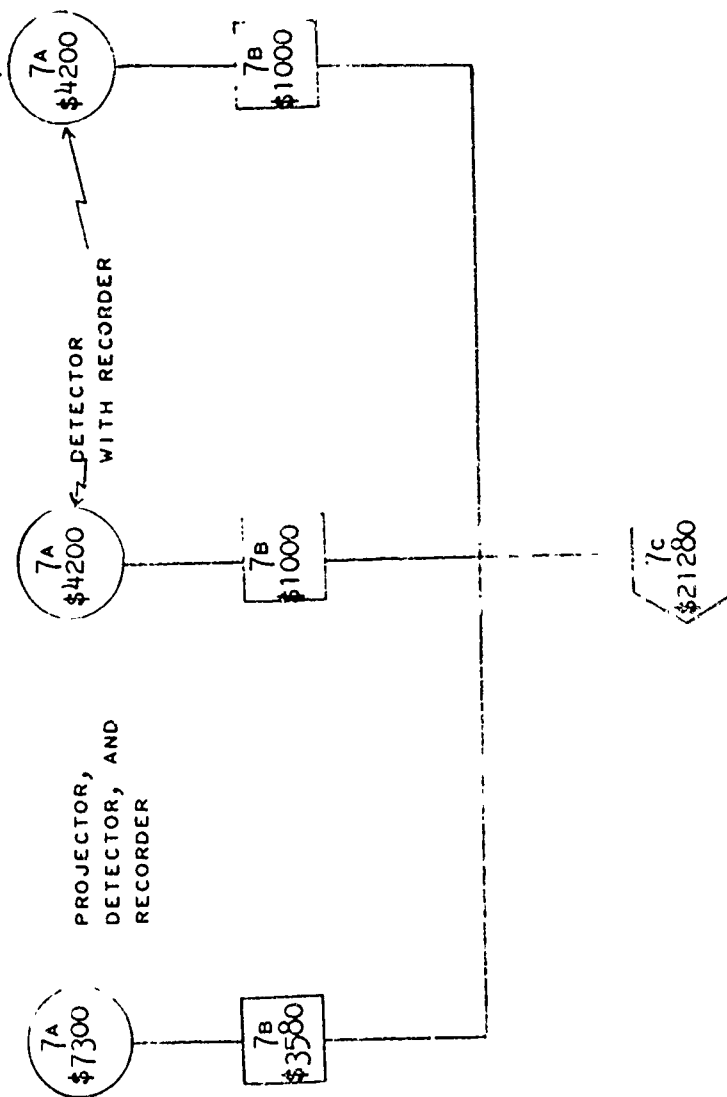


6. TRANSMICSOMETER SYSTEMS  
 A. ACQUISITION  
 B. INSTALLATION AND CABLING  
 C. TOTAL

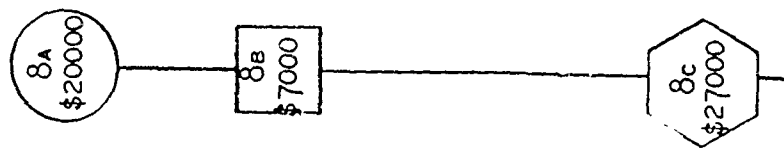


# 7. ROTATING BEAM CEILOMETER

A. ACQUISITION  
B. INSTALLATION AND CABLING  
C. TOTAL



8. DATA LOGGING SYSTEM



9. CRANKUP TOWER

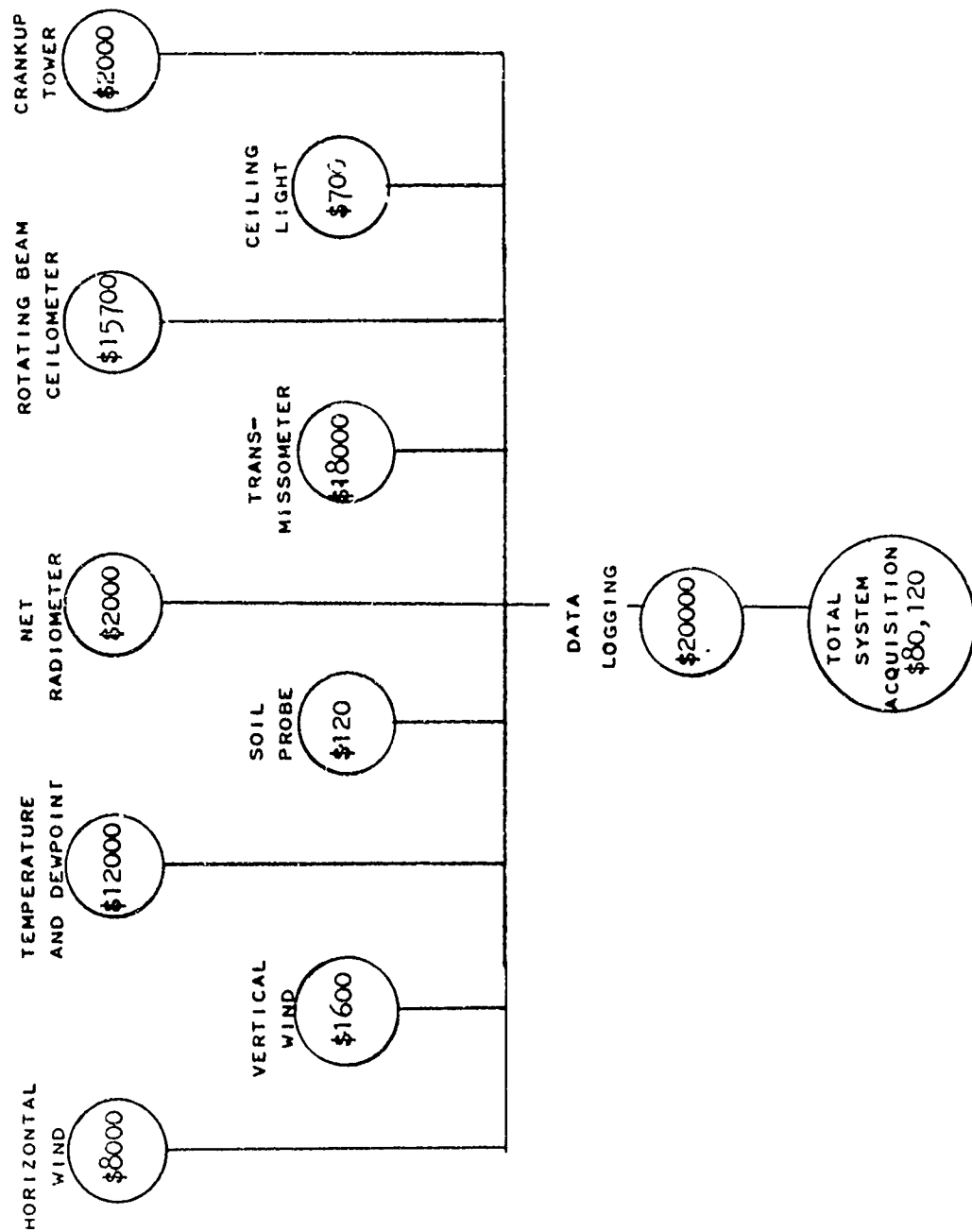
- A. ACQUISITION
- B. INSTALLATION
- C. TOTAL



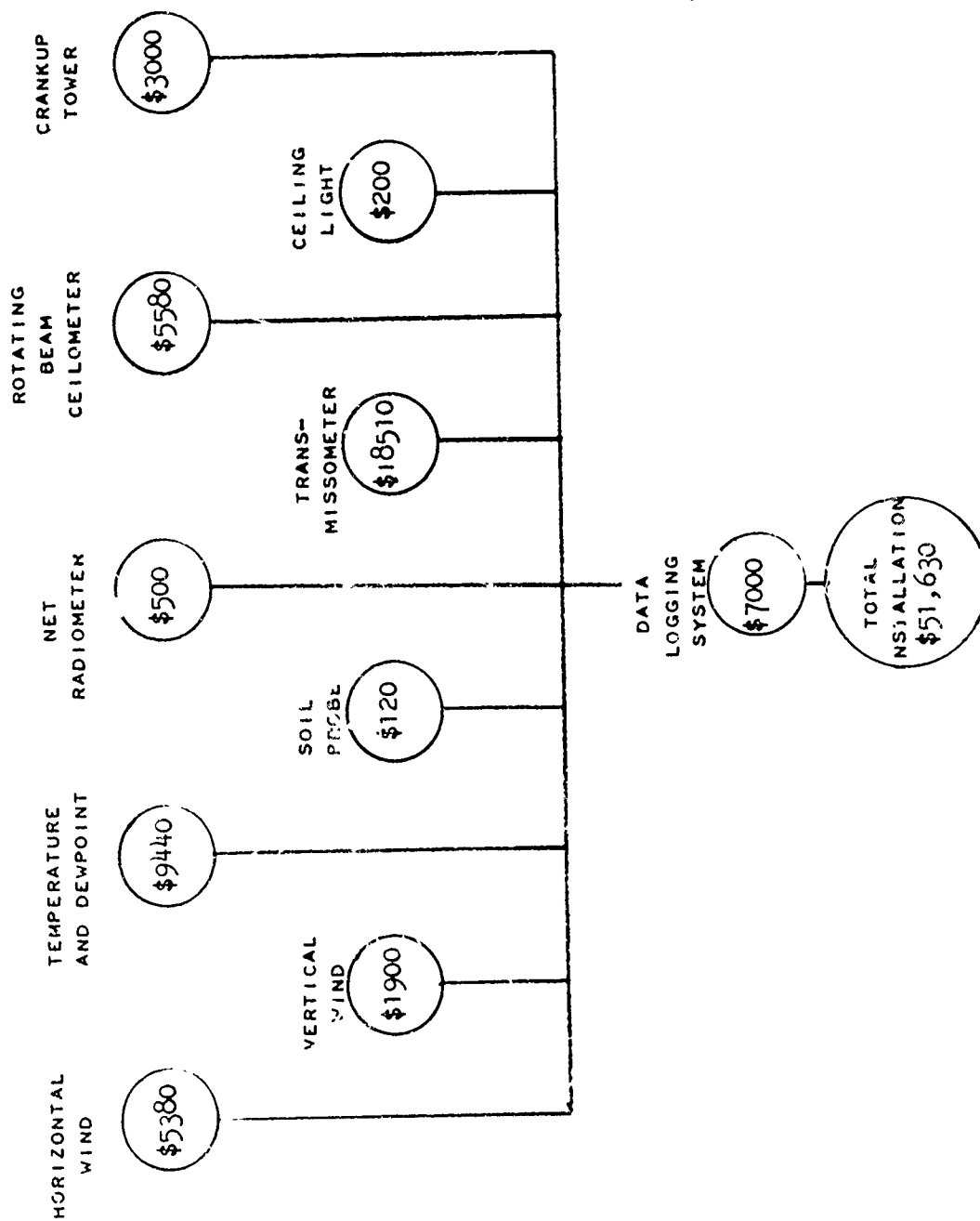
10. CEILING LIGHT



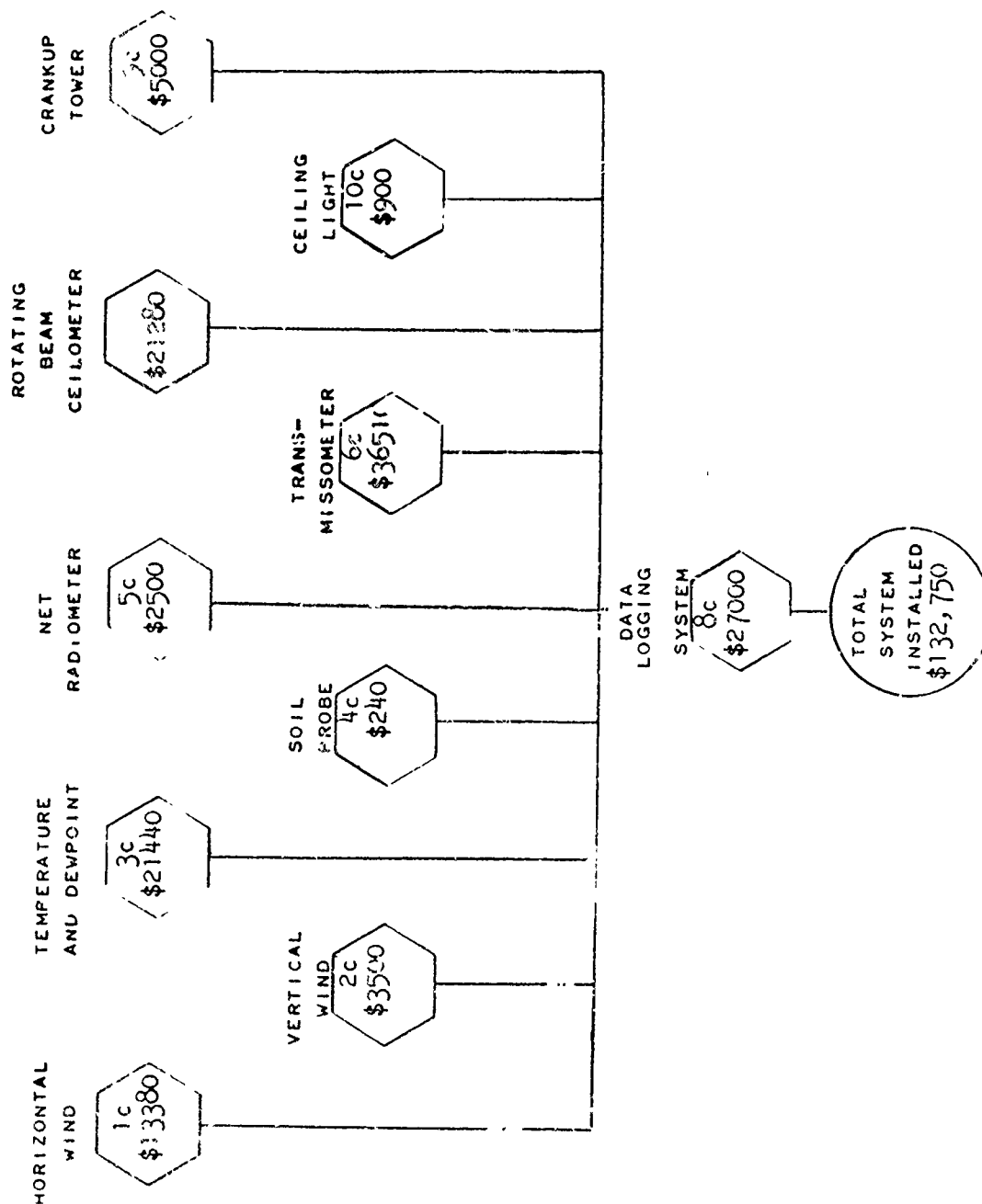
# SYSTEM ACQUISITION



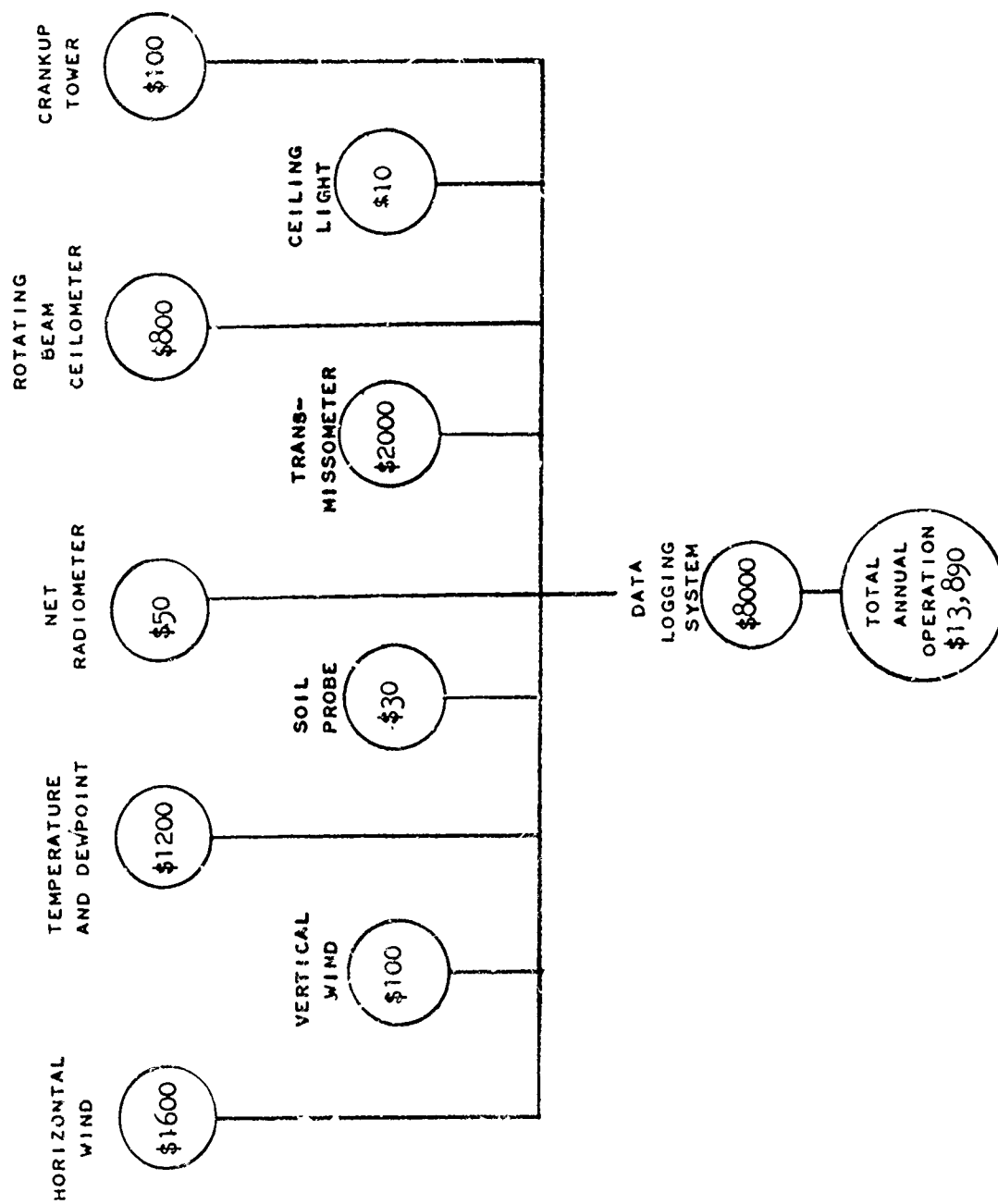
# SYSTEM INSTALLATION (INCLUDING CABLING)



# SYSTEM ACQUISITION AND INSTALLATION COMBINED

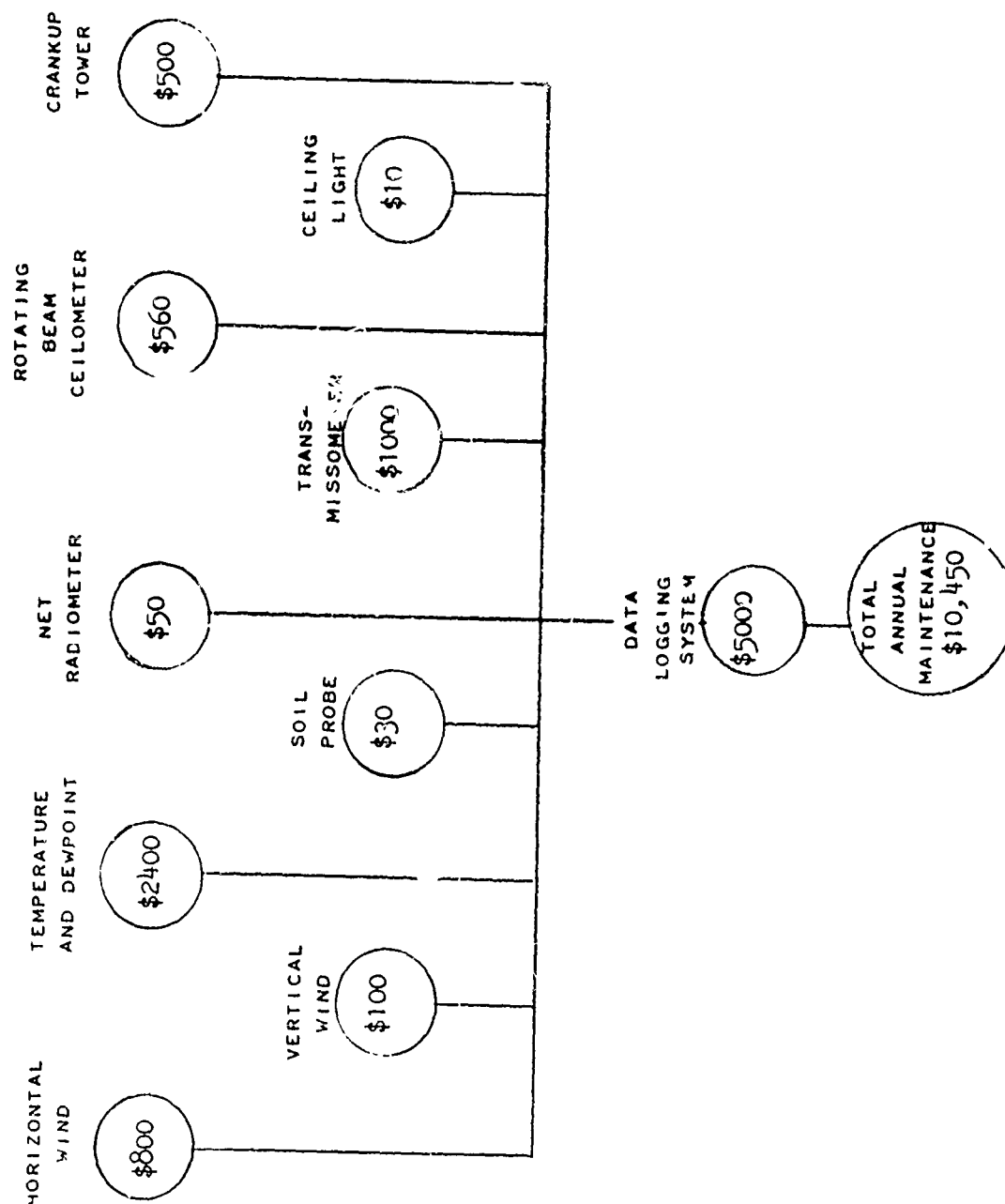


# ANNUAL OPERATION



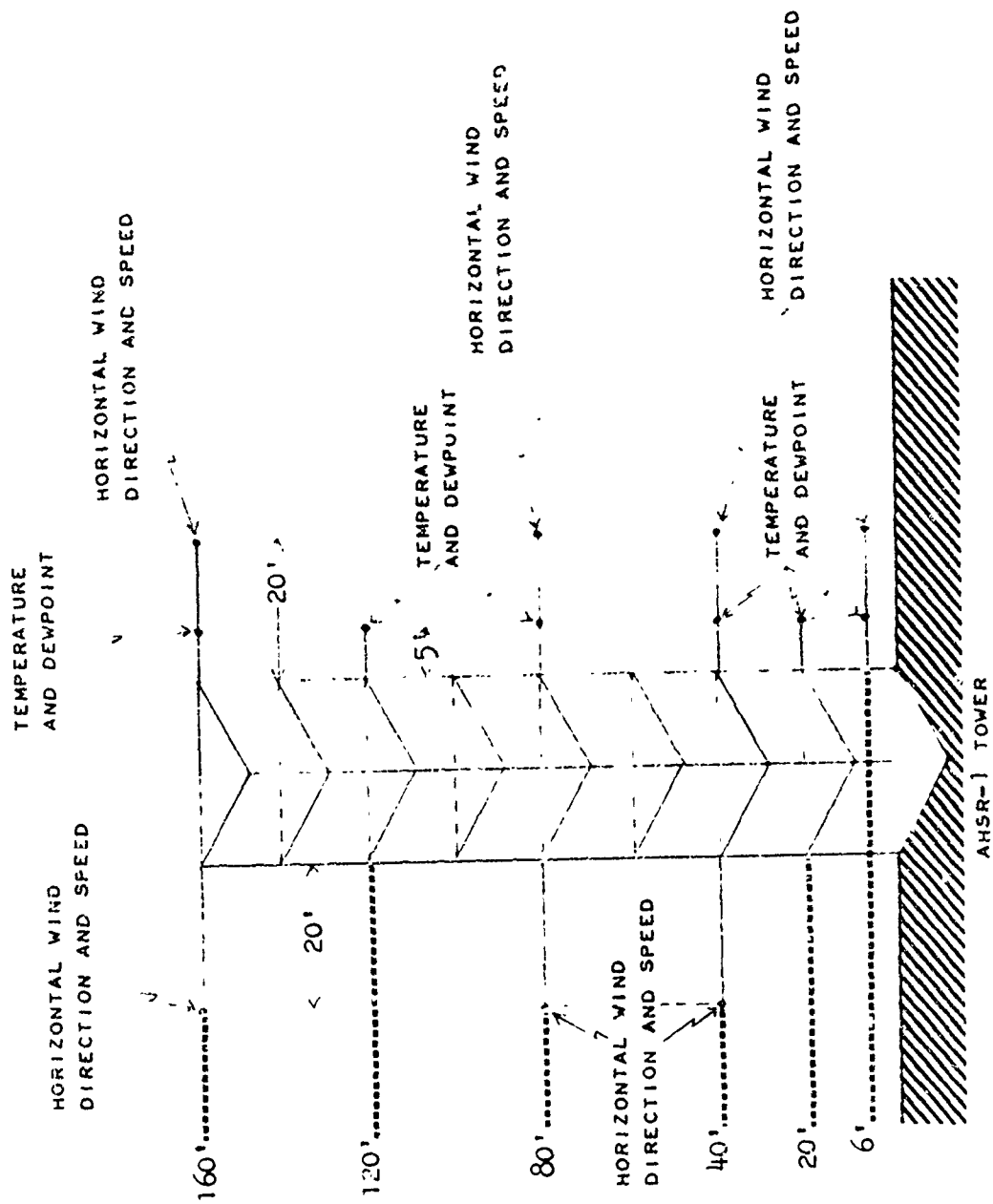


# ANNUAL MAINTENANCE

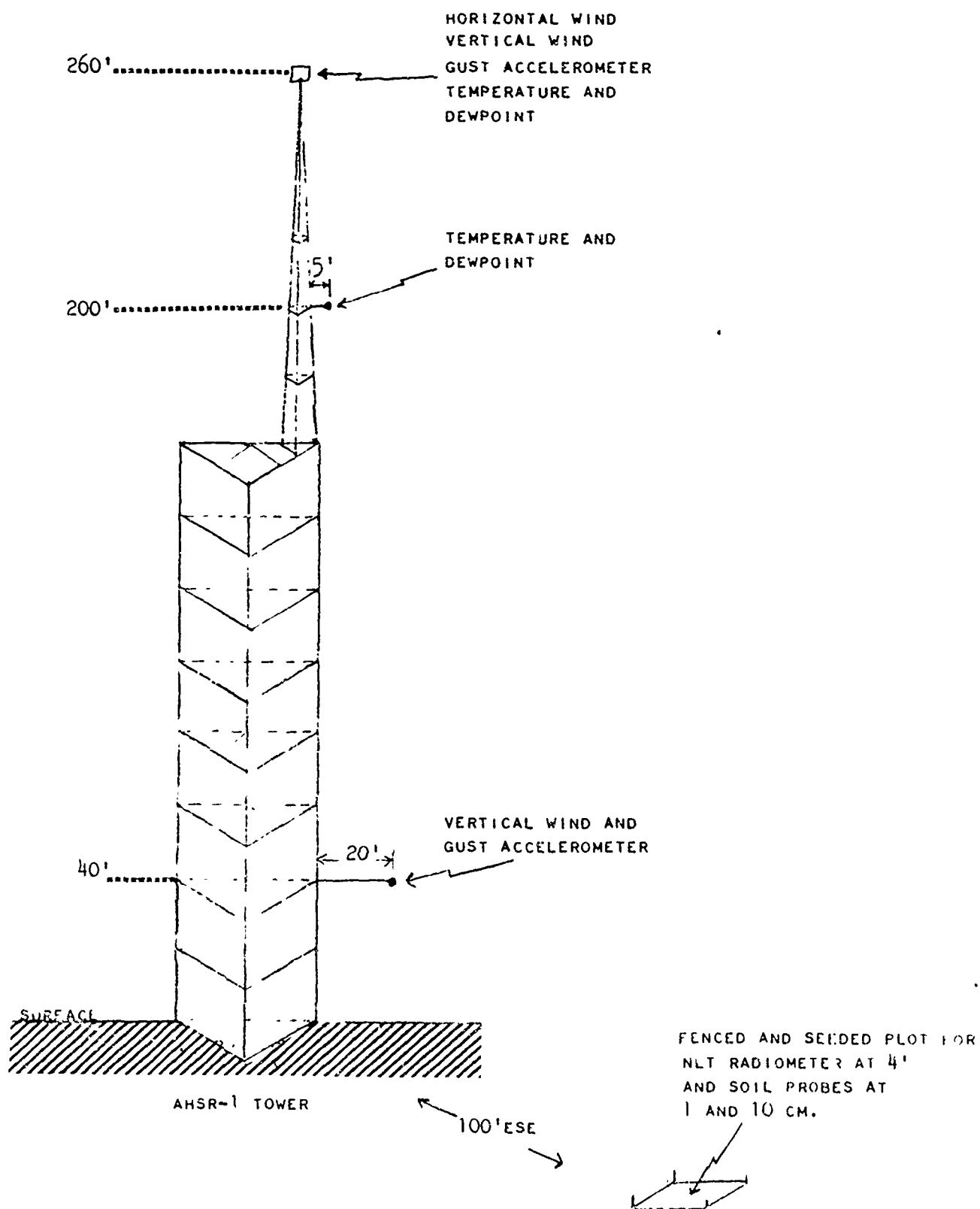


## APPENDIX C

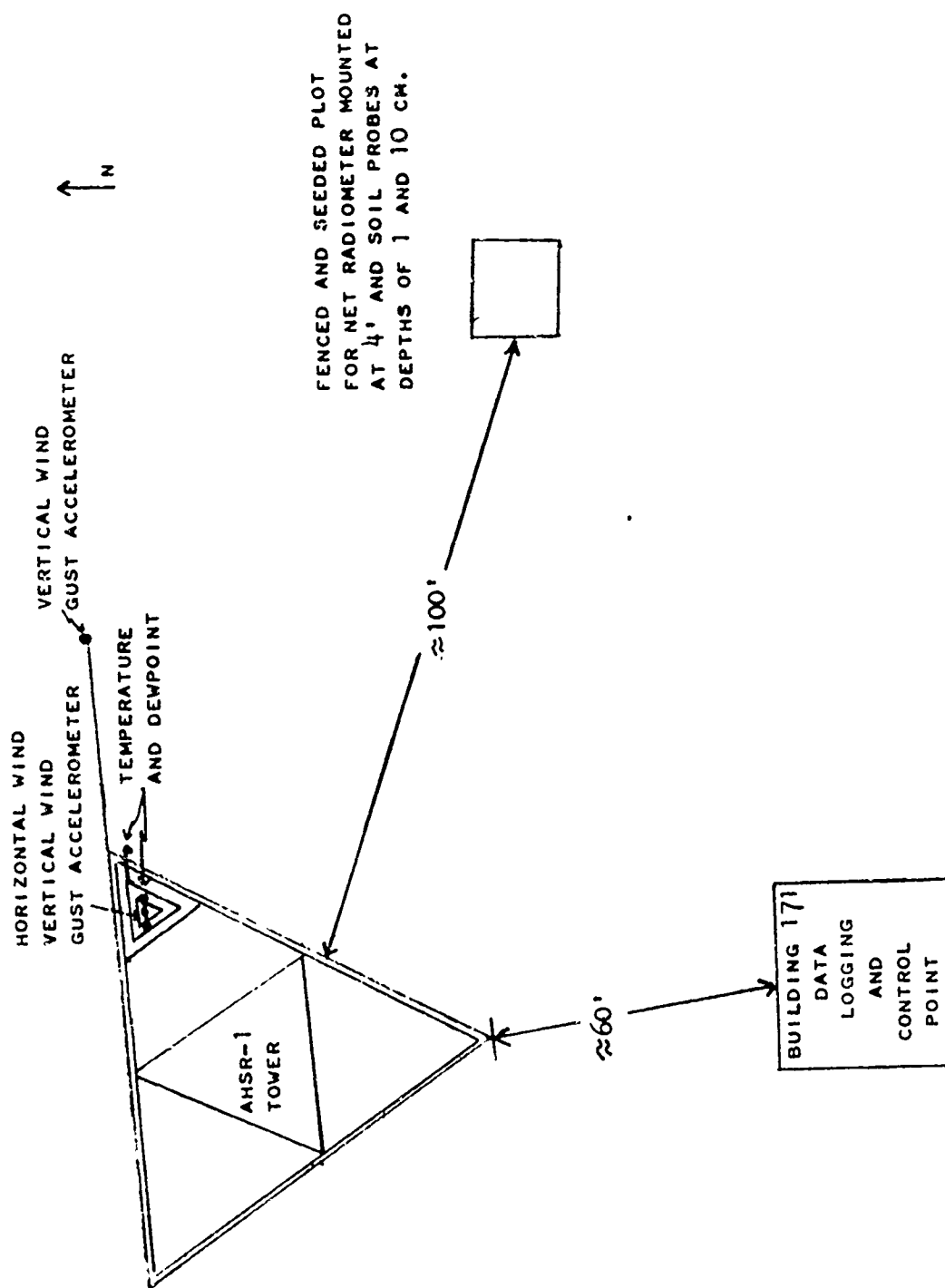
### SUMMARY OF METOWER SYSTEM DESIGN



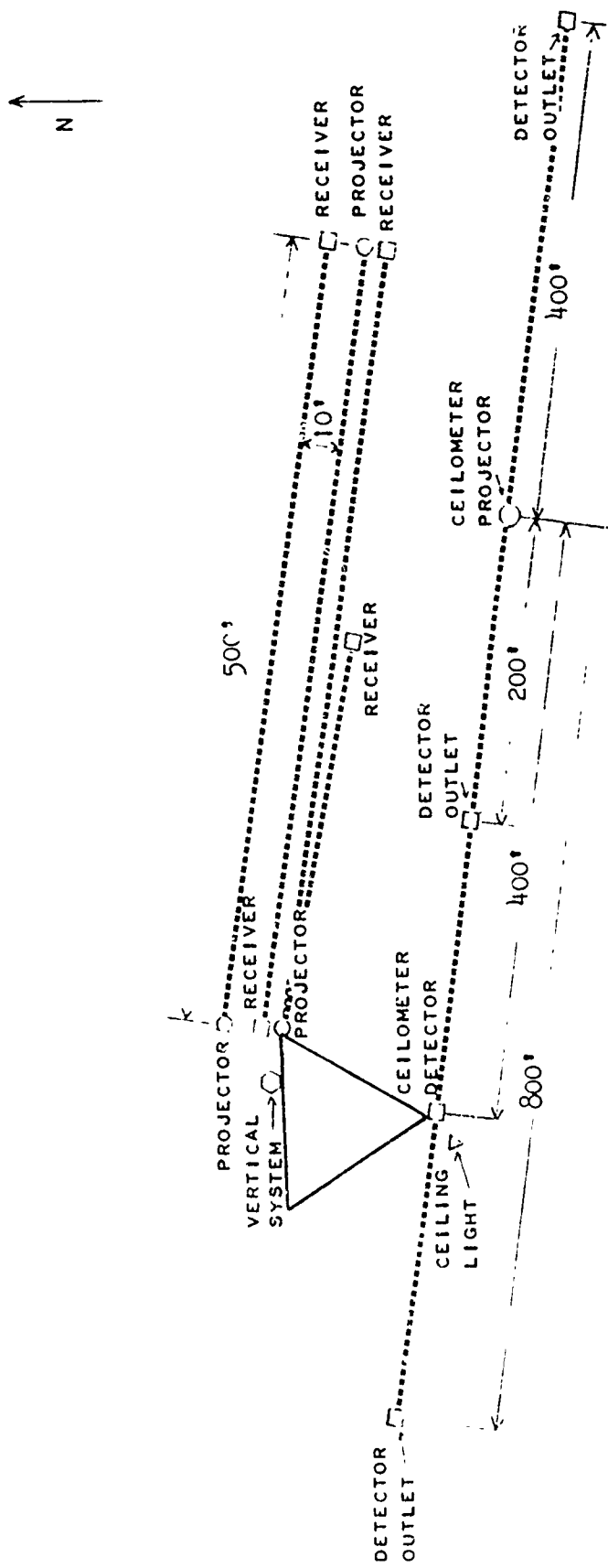
TOWER INSTRUMENTATION FOR PROFILES OF WIND, TEMPERATURE, AND DEWPOINT, AS SHOWN IN "ENGINEERING REQUIREMENT OF A METEOROLOGICAL TOWER FACILITY", DRAFT OF MARCH 15, 1967 (PAGES C-7 TO C-18)



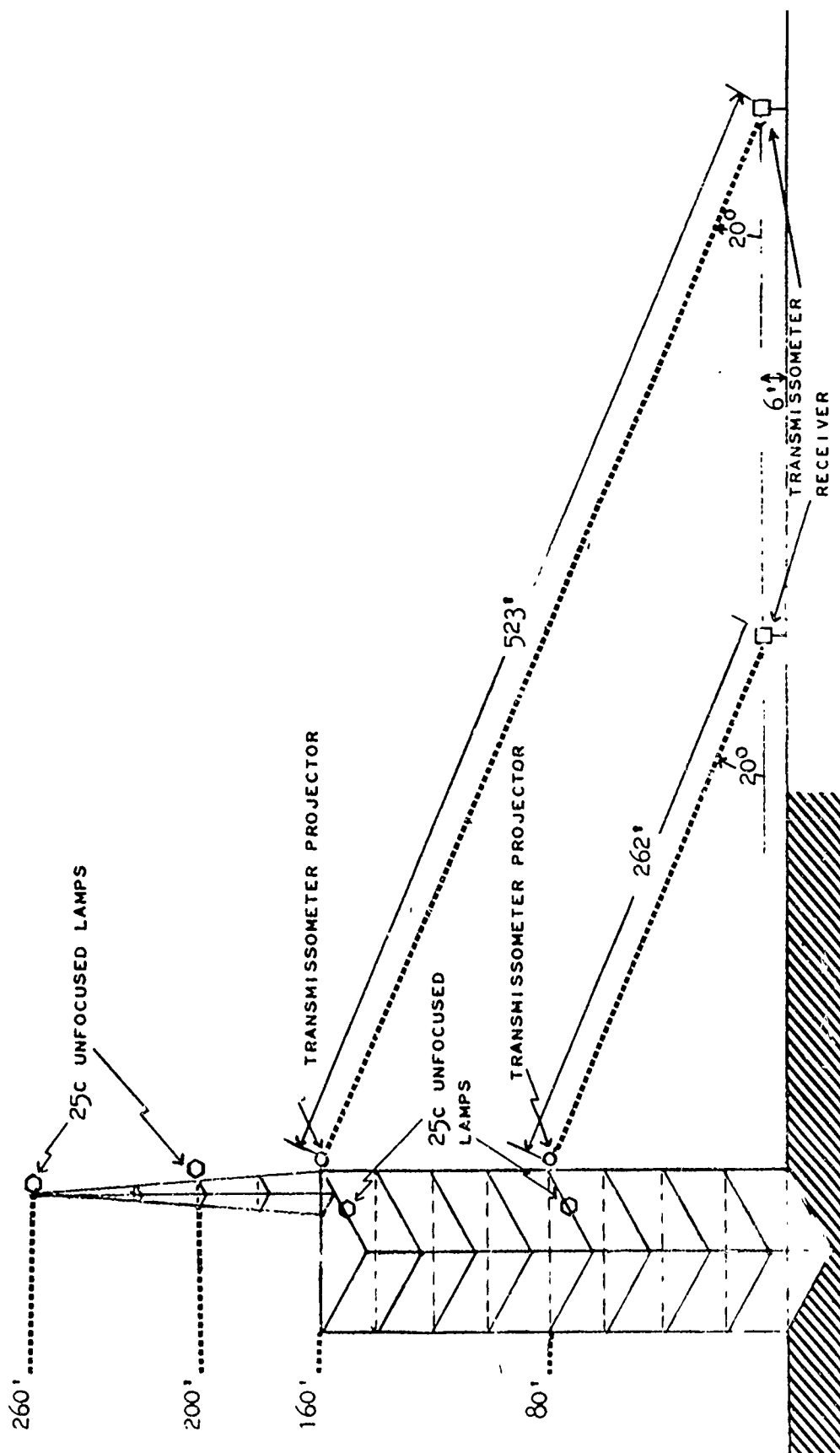
SIDE VIEW OF SUPPLEMENTARY TOWER INSTRUMENTATION OF WIND,  
TEMPERATURE, DEWPOINT, AND NET RADIATION REQUIRED BY METOWER  
FACILITY



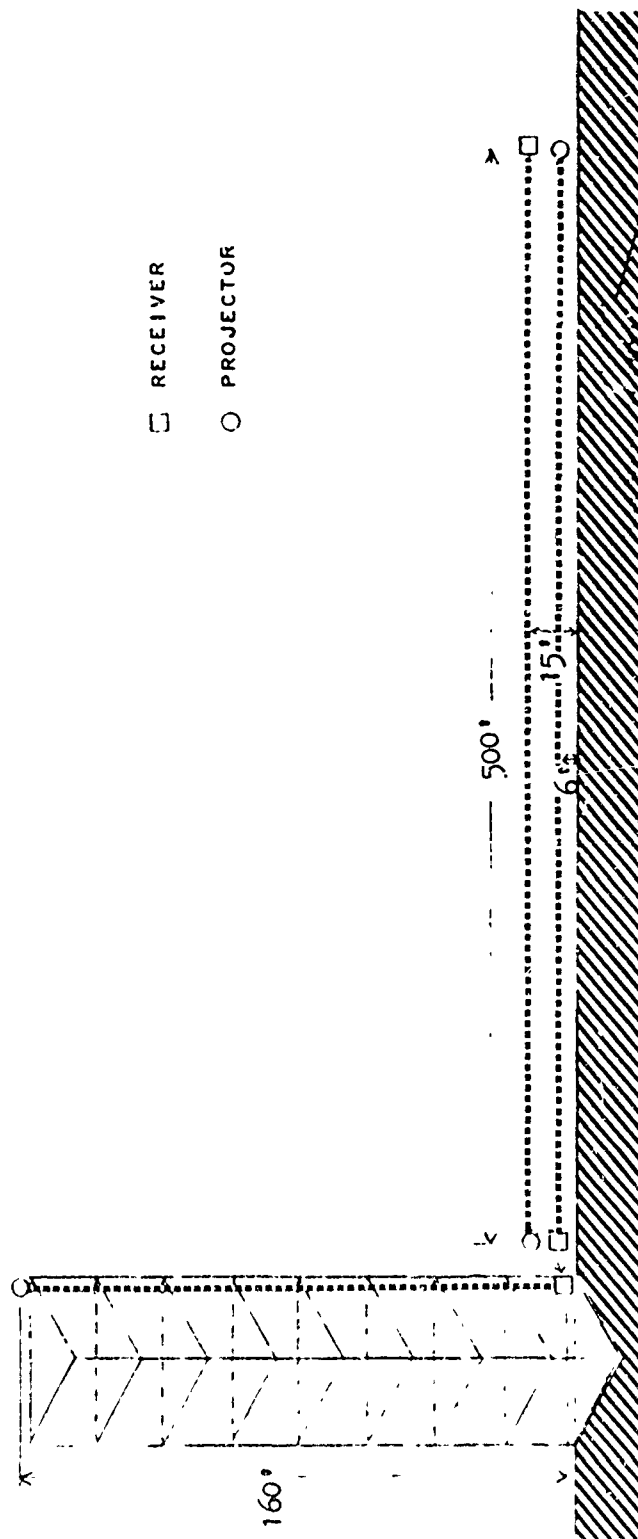
TOP VIEW OF SUPPLEMENTARY TOWER INSTRUMENTATION OF WIND, TEMPERATURE, DEWPOINT, AND NET RADIATION REQUIRED BY MET TOWER FACILITY



TOP VIEW OF TRANSMISSOMETER AND ROTATING BEAM CEILOMETER  
CONFIGURATIONS REQUIRED BY METOWER FACILITY



3<sup>A</sup>  
 SIDE VIEW OF SLANT TRANSMISSOMETER CONFIGURATION & INSTRUMENTATION FOR HUMAN  
 OBSERVATIONS OF SLANT & VERTICAL VISIBILITY REQUIRED BY THE METOWER FACILITY



SIDE VIEW OF HORIZONTAL AND VERTICAL TRANSMISSOMETER  
CONFIGURATIONS REQUIRED BY METOWER FACILITY



FEDERAL AVIATION AGENCY  
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER  
ATLANTIC CITY, NEW JERSEY

ENGINEERING REQUIREMENT  
FOR  
INSTRUMENTATION OF A METEOROLOGICAL TOWER FACILITY

ER-TP-738-117-00T

, 1967

Draft: March 15, 1967

ENGINEERING REQUIREMENT  
FOR  
INSTRUMENTATION OF A METEOROLOGICAL TOWER FACILITY

1. INTENTION

The Contractor shall furnish, install, test, and calibrate, in accordance with the requirements set forth herein, instrumentation and appurtenances to measure and record meteorological information from a tower. The Contractor shall furnish, with the exceptions noted in this Engineering Requirement, all labor, materials, and equipment, subject to the terms of the Contract, complete and ready to use. The system procured hereunder shall be operated by the Government.

1.1 DESCRIPTION

In general, this Engineering Requirement requests the Contractor to provide the necessary instrumentation on an existing 160-foot tower. The purpose is to acquire data on which to base studies of the effects of the fundamental physical processes of the lowest layers of the atmosphere, in a vertical profile, on aviation terminal weather variations and short-range aviation terminal forecasts.

1.2 LOCATION

The system shall be installed, tested, and calibrated on the ANSR-1 tower and in Building 171 located at the National Aviation

Facilities Experimental Center, (NAFEC), Atlantic City, N. J.

### 1.3 TIME

The existing AHSR-1 tower structure will be modified by the Government to be established as a meteorological test-bed facility. Upon completion of the modification, the tower will be made available to the Contractor. The system shall be installed, calibrated, and operational within 90 days after the tower is made available.

### 2. ENVIRONMENTAL REQUIREMENTS

Design, materials, and workmanship shall be of first-class quality. The entire system, without exception, shall be able to withstand, without damage or performance degradation, exposure to wind speeds up to 99 knots; temperature ranges from -30°C to 45°C; relative humidity from 30% to 100%; weather elements such as rain, snow, sleet, dust, etc.; and such atmospheric constituents typical of the Southern New Jersey coastal area.

### 3. SYSTEM DESIGN

The Contractor shall fabricate, provide, install, and calibrate a meteorological sensing and recording system on the modified AHSR-1 tower and in Building #171 at NAFEC to satisfy this system design. The system shall contain sensors, sensor supports, data acquisition, transmission, control and recording devices, and related components acceptable for meteorological observations.

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### 3.1 TOWER LEVELS OF INSTRUMENTATION

All sensors shall be installed on suitable booms as specified in this ER. The booms shall be installed at the following heights above the concrete base of the tower:

|           |                       |
|-----------|-----------------------|
| Level 1 : | 5 feet $\pm$ 1 foot   |
| Level 2 : | 30 feet $\pm$ 2 feet  |
| Level 3 : | 49 feet $\pm$ 2 feet  |
| Level 4 : | 86 feet $\pm$ 2 feet  |
| Level 5 : | 124 feet $\pm$ 2 feet |
| Level 6 : | 159 feet $\pm$ 2 feet |

### 3.2 BOOM DESIGN

The Contractor shall supply instrumentation booms in accordance with the schedule herein and paragraph 3.1. Booms shall be of a material to function satisfactorily under the environmental requirements previously noted (paragraph 2). The booms shall be of a design which will adequately support the sensors and that vibration and undesired motion shall be sufficiently low as not to impart characteristics to acquired data, or to affect sensor accuracy or calibration. The Contractor shall design, fabricate, and install the booms on the tower. The installation shall include a means by which the booms may be easily retracted in such a manner that all sensors mounted on the booms are safely accessible from the tower platform without risk to personnel or damage to equipment. Means shall be provided for retraction and extension of the booms without change in boom orientation. Booms, in general, shall be mounted

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parallel to the north face of the tower, extending outward from the east and west corners of the tower. Following is the boom schedule:

Level 1 : Boom extending 20 feet ( $\pm 1'$ ) from the outermost point of the eastern corner of the tower structure, oriented toward  $085^\circ$  true ( $\pm 5^\circ$ ).

Level 2 : Boom extending 6 feet ( $\pm 1'$ ) from the outermost point of the eastern corner of the tower structure, oriented toward  $085^\circ$  true ( $\pm 5^\circ$ ).

Level 3 : One boom extending 20 feet ( $\pm 1'$ ) from the outermost point of the eastern corner of the tower structure oriented toward  $085^\circ$  true ( $\pm 5^\circ$ ); one boom extending 20 feet ( $\pm 1'$ ) from the outermost point of the western corner of the tower structure oriented toward  $265^\circ$  true ( $\pm 5^\circ$ ).

Level 4 : One boom extending 20 feet ( $\pm 1'$ ) from the outermost point of the eastern corner of the tower structure oriented toward  $085^\circ$  true ( $\pm 5^\circ$ ); one boom extending 20 feet ( $\pm 1'$ ) from the outermost point of the western corner of the tower structure oriented toward  $265^\circ$  true ( $\pm 5^\circ$ ).

Level 5 : Boom extending 6 feet ( $\pm 1'$ ) from the outermost point of the eastern corner of the tower structure, oriented toward  $085^\circ$  true ( $\pm 5^\circ$ ).

Level 6 : One boom extending 20 feet ( $\pm 1'$ ) from the outermost point of the eastern corner of the tower structure oriented toward  $085^\circ$  true ( $\pm 5^\circ$ ); one boom extending 20 feet ( $\pm 1'$ )

from the outermost point of the western corner of the tower structure oriented toward 265° true ( $\pm 5^\circ$ ).

### 3.3 INSTRUMENTATION

The system shall contain sensors suitable for meteorological observations, and shall be capable of continuous unattended operation except for normal maintenance and calibration. For each parameter measured sensor design and type shall be identical throughout the system. The Contractor shall supply, install, test, and calibrate the sensors in accordance with the following specifications:

#### 3.3.1 WIND

Wind sensors shall be located within 1 foot of the outermost point of the boom, and mounted 1 to 2 feet above the upper edge of the boom, at Levels 1, 3 (both booms), 4 (both booms), and 6 (both booms).

Wind data output from sensor through recording shall meet the following specifications:

|                | <u>Range</u>  | <u>Accuracy</u> | <u>Resolution</u> | <u>Starting Speed</u> |
|----------------|---------------|-----------------|-------------------|-----------------------|
| Wind direction | 1° to 360°    | $\pm 5^\circ$   | 1°                | $\leq 1$ knot         |
| * Wind speed   | 0 to 99 knots | $\pm 1$ knot    | 1 knot            | $\leq 1$ knot         |

\* Wind speed output shall represent a one minute average.

Direction and speed sensors shall be so combined or mounted so that they shall not interact in operation.

#### 3.3.2 AIR TEMPERATURE

Air temperature sensors shall be located on the booms 5 feet from

DRAFT: March 15, 1967

the outermost portion of the tower structure and mounted 1 foot below the lowest edge of the boom. They shall be installed at all 6 levels on the booms oriented 085°. Proper radiation and weather shielding shall be provided by the Contractor, and the sensor aspirated in a manner suitable for the unit. The air temperature data output from sensor through recording shall meet the following specifications:

| <u>Range</u>   | <u>Accuracy</u> | <u>Resolution</u> |
|----------------|-----------------|-------------------|
| -20°C to +40°C | ±0.6°C          | 0.1°C             |

### 3.3.3 DEW POINT TEMPERATURE

Dew point sensors shall be located on the booms adjacent to the air temperature sensors. They shall be mounted in such a manner that there shall be no interaction between air and dewpoint temperature sensors. Proper radiation and weather shielding shall be provided by the Contractor and the sensor aspirated in a manner suitable for the unit. The lithium chloride principle of dewpoint measurement is acceptable. The dewpoint data output from sensor through recording shall meet the following specifications:

| <u>Range</u>   | <u>Accuracy</u> | <u>Resolution</u> |
|----------------|-----------------|-------------------|
| -20°C to +30°C | ±0.8°C          | 0.1°C             |

### 3.4 DATA ACQUISITION SYSTEM

Data acquisition and control equipment will be supplied, tested, calibrated, and installed by the Contractor approximately 100 feet from the base of the tower in Building 171 at NAFEC. The Contractor may use existing ductwork if desired. If Contractor

elects not to use available ductwork, he shall use suitable direct burial techniques and cables, restoring the area to original condition upon completion.

The Government will supply one pair of twisted, shielded #22 AWG wire terminating at the eastern corner of the tower to each of the 6 levels, and also terminating in Building 171. This represents a total of 6 pairs of twisted, shielded #22 AWG wire. The Government will supply an additional single, shielded, twisted pair of #22 AWG wire with access points at each level on the eastern corner of the tower and in Building 171. This may be used as a control loop if required by the Contractor.

The Government will supply at the eastern corner of the tower at each level two 15 amp 115 VAC 60 cycle power circuits. Any additional power and cabling requirements of the Contractor for the operation of his system must be supplied, installed, and properly terminated by the Contractor.

#### 3.4.1 SYSTEM CONTROL AND OBSERVATIONS

The system shall be capable of operation by remote control from the data-receiving point in Building 171. This control shall include the selection of data sampling and recording modes. Data recording rates shall be selectable by the operator at the receiving point and shall be complete observations at intervals of 1, 10, 30, or 60 minutes. There shall be two observational modes selectable by the operator at the data receiving point.

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OBSERVATION MODE 1. A near instantaneous sampling of all parameters measured on the tower. The observation sequence shall begin with the lowest level and proceed to the uppermost tower level. Each observation shall include all parameters measured at each level as well as the Julian date, hours and minutes (24 hour clock) of the beginning of the observation. The time interval to sample and record each observation shall not exceed 20 seconds.

OBSERVATION MODE 2. A near instantaneous sampling of all parameters measured at any single level on the tower, the level to be selected by remote control at the option of the operator. Each observation shall include all parameters measured at the selected level as well as the Julian date, hours and minutes (24 hour clock) of the beginning of the observation. The time interval to sample and record each observation shall not exceed 20 seconds.

#### 3.4.2 DATA OUTPUT

Final data output shall be in the form of standard IBM type 80-column punch cards, both punched and printed simultaneously, as performed by an IBM printing card punch type 026, or equivalent. Format of the punch card shall be such that data from each tower level appears in the same card location throughout observation cycles and in all observation modes. Provision shall be made in the system so that the operator may at his option cause the system to not record a sensor or sensors at any level continuously until the operator restores the system to normal operation. This provision shall not cause changes in the accepted card format.

The data output device shall be capable of unattended operation for a minimum of 48 hours at one observation per minute.

Data output as recorded and punched on the punch card shall be in such format and/or code as not to require more than one card for each observation. Format and/or code shall be at the Contractor's option but as a minimum shall record:

Julian day

Hour and minute to the minute at the beginning of the observation

Wind direction to the nearest degree, true

Wind speed to the nearest knot

Air temperature to the nearest 0.1°C

Dewpoint to the nearest 0.1°C

#### 4. POWER REQUIREMENT

The system shall be capable of operating on 115 VAC 60 cycle with a  $\pm 10V$  power variation causing no degradation to the system or operation.

#### 5. INSTALLATION

The entire system shall be installed, tested, calibrated, and left in a satisfactory operating condition by the Contractor. Installation shall include component of proper size and material. The Contractor shall provide adequate lightning protection for the entire system. Booms and other tower equipment shall be connected to the tower in such a manner that calibration and maintenance may be performed by regular personnel rather than tower personnel.

without special risk of injury or need for special safety equipment. Safety of personnel will be a major consideration.

#### 6. GOVERNMENT-FURNISHED EQUIPMENT

The Government shall furnish:

The modified AHSR-1 tower, including landings, guard rails, illumination, and a 300 pound capacity elevator to 140 feet.

One pair of twisted shielded #22 AWG wire terminating at the eastern corner of the tower to each of the 6 levels, and also terminating in Building 171.

One single pair of shielded twisted #22 AWG wire with access points at each level on the eastern corner of the tower and in Building 171.

Two 15 amp 115 VAC 60 cycle power circuits at each of the 6 levels on the eastern corner of the tower.

Ducting from the tower to Building 171,

Space in Building 171 for recording and control equipment.

#### 7. DOCUMENTATION

The Contractor shall provide the following documentation.

##### 7.1 TEST SPECIFICATIONS

The Contractor shall prepare and submit recommended test and calibration methods to demonstrate compliance with the specifications to the Contracting Officer. The test and calibration methods shall be a comprehensive document including all details necessary to ensure that test and calibration methods will satisfactorily

demonstrate equipment compliance with all functional, environmental, electrical, mechanical, and reliability requirements of the contract. The Government has the right to witness any and all tests conducted on the equipment by the Contractor and to perform other testing as deemed necessary.

The Contractor shall furnish all specialized calibration equipment unique to his system or not readily obtained on the open market such as test spools, wind direction orientation jigs, wind speed calibrator and the like.

#### 7.2 INSTRUCTION MANUALS.

Ten copies of system and equipment instruction manuals shall be provided by the Contractor. These manuals shall include, but shall not be limited to, the following areas:

- System operational procedures,

- System maintenance,

- Calibration procedures and test instrumentation required,

- System repair and troubleshooting procedures and techniques,

- Lists of all major component parts used in the system. The manufacturer's name and part number shall be indicated for each item, as well as the symbol number and description,

- A description of all sensors and their technical characteristics,

- A complete explanation, description, and code book if necessary, for data output interpretation.

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### 7.3 INSPECTION AND ACCEPTANCE

Final inspection and acceptance of the system procured shall be made at Building 171 and the AHSR-1 tower by authorized representatives of the Federal Aviation Administration.

APPENDIX D

ENGINEERING REQUIREMENT ON  
WHICH EFFORT WAS BASED

## APPENDIX D

The following is the Engineering Requirement on which this effort was based. It is provided as a frame of reference for elements of this report.

FAA-ER-450-016  
September 16, 1966

### FEDERAL AVIATION AGENCY ENGINEERING REQUIREMENT

#### ANALYSIS OF DESIGN CHARACTERISTICS OF METEOROLOGICAL TOWER FACILITY

##### 1. SCOPE

1.1 Scope.- This Engineering Requirement (ER) specifies the work required for establishment of design parameters for subsequent modification and instrumentation of the Meteorological Tower Facility (Metower) test bed at the National Aviation Facilities Experimental Center (NAFEC). The work shall incorporate analysis of instrumentation required to measure transmittance profiles, cloud bases, wind profiles, aerosols, and wind shear as applicable to approach and landing turbulence. Instrumentation to be used for measuring supporting parameters will also be investigated. This ER embodies analysis of the proposed modification and validation of the same by limited experimental studies.

##### 2. APPLICABLE DOCUMENTS

2.1 FAA specification.- The following FAA specification of the issue specified in the invitation for bids or request for proposals, forms a part of this ER and is applicable to the extent specified herein.

FAA-D-2129 Contractor Prepared Technical Reports, Research  
and Development Contracts

(Copies of this ER and the other applicable FAA specification may be obtained from the Federal Aviation Agency, Washington, D. C. 20553,

ATTN: Contracting Officer. Requests should fully identify material desired, i.e., specification number and data. Requests should cite the invitation for bids, request for proposals, or contract involved or other use to be made of the requested material).

### 3. REQUIREMENTS

3.1 General.- Work encompassed in the ER includes analysis of the design characteristics of a test bed based on, but not restricted to, the metower at NAFEC. Nature of the analysis shall primarily be a literature survey. The objective will be to provide guidance to the FAA, using published research reports and interviews, in the preparation of other ERs, test plans and research efforts. Limited experimentation, as feasible will be conducted to validate design choices. Analysis shall include recommendations regarding sensor characteristics, sensor spacing and orientation, and configuration. Sensors need not be restricted to physical installations on the metower. Recommendations regarding the feasibility of utilizing human observations to corroborate instrumentally derived values shall be incorporated.

3.2 Visibility profiles.- Necessary experimental work, as feasible, shall be accomplished to validate the metower as a platform to affix components of transmissometer systems. Tests will be accomplished to ascertain if valid measurements may be taken in slant, vertical or horizontal configurations. Experimentation shall be conducted in various tower exposures of the transmissometer. Prototype sensors, if available during the test period, will be furnished by the FAA and included in the program. Recommendations regarding required supplemental meteorological instrumentation shall be incorporated.

3.3 Cloud base studies.- The feasibility of determining vertical visibility through the use of transmissometer and ceilometer sensors shall be explored. Techniques for calibrating and validating ceilometer observations shall be studied.

3.4 Wind, temperature, and dewpoint profiles.- An analysis of the existing instrumentation on the metower to adequately describe low level horizontal wind profiles and to provide supporting data for other studies encompassed by this ER shall be accomplished. The desirability of using sensors capable of measuring three dimensional wind components shall be analyzed



3.5 Wind shear and low level turbulence.- An analysis of the instrumentation required to adequately describe wind shear and low level turbulence shall be included.

3.6 Aerosol measurements.- An analysis of instrumentation required to acquire information regarding the aerosol constituents of low clouds and obstructions to vision shall be conducted.

3.7 Reports.- All reports shall be supplied in accordance with specification FAA-D-2129 except as herein modified:

- (a) An SRDS report number will not be assigned.
- (b) Abstract cards will not be required.
- (c) A Network Milestone Chart (or Part Network Chart) not be required.
- (d) The final report shall be reproduced by any process suitable to assure clear, sharp reproduction.
- (e) Cover stock specified is not a requirement.

3.7.1 Submission of reports.- A minimum of five (5) review copies of the final report shall be submitted to the Contracting Officer's technical representative (COTR) for review and approval. Twenty (20) reproduced copies of the approved final report shall be submitted to the COTR in accordance with the instructions furnished upon approval of the review copy.

3.8 Cost information.- A detailed cost break-out of the test beds recommended shall be included in the final report. Costs shall be reported in such detail that sensor acquisition, installation, operation and maintenance costs may be distinguished. Data acquisition, reduction and analysis costs shall be furnished. Costs shall be presented in a manner to facilitate implementation of recommendations specified in the final report by whole or by part in order to facilitate implementation of discrete parts of the recommendations.

#### 4. QUALITY ASSURANCE PROVISIONS

4.1 Not applicable

#### 5. PREPARATION FOR DELIVERY

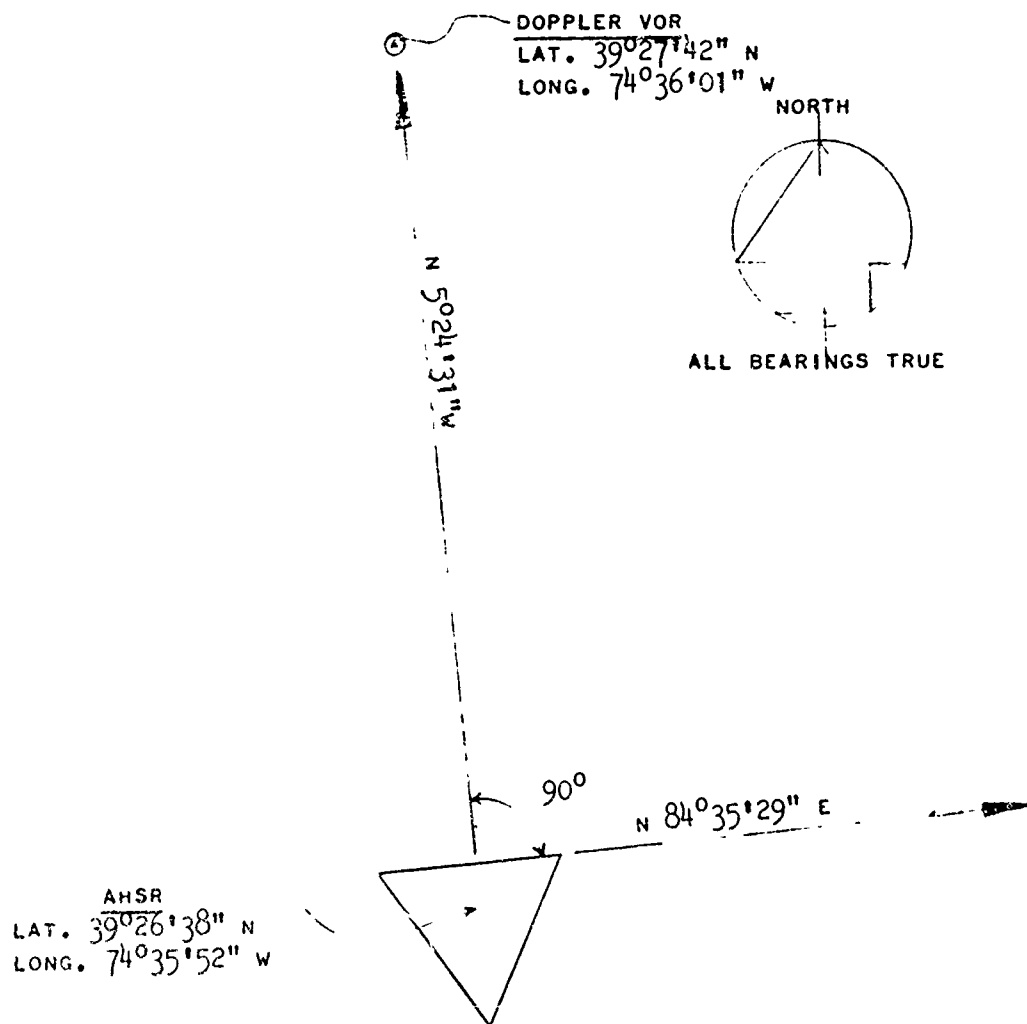
5.1 Not applicable

#### 6. NOTES

6.1 None

ADDENDUM

FEDERAL AVIATION ADMINISTRATION  
N.A.F.E.C.  
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